Manitoba
Agriculture

Papers
presented at the
31st ANNUAL
MANITOBA SOCIETY OF SOIL SCIENCE MEETING

January 5 and 6, 1988

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88-04642/

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31ST ANNUAL

MANITOBA SOCIETY
SOIL SCIENCE MEETING

HOLIDAY INN SOUTH
(Winnipeg)

January 5 and 6, 1988

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SUMMARY OF SOIL SURVEY PROJECTS IN MANITOBA

G.F. Mills and R.E. Smith
Canada-Manitoba Soil Survey

The activities of the joint Canada-Manitoba Soil Survey during the period April, 1987 to March 31, 1988 continue to include land inventory and a supporting program of research and development. The land inventory activities respond to priorized needs by Departments of Agriculture, Municipal Planning, Forestry and Environment. A supporting research program is continuing in soil classification, soil characterization and land resource evaluation. In addition, development of a soil resource data management system for Manitoba is on-going to enable more quantitative assessment of land productivity and soil degradation.

SOIL INVENTORY

Detailed resurvey of approximately 88,500 ha (345 sq. miles) at 1:20,000 scale were completed in the R.M.'s of North Norfolk (D80) and Rhineland (D76). These surveys are continuing and will be completed in 1988. A special study of soil conditions in the Oak Lake-Plum Lakes area was carried out to provide background soil resource information for on-going land use studies. This survey provided detailed soil information for approximately 15,000 ha (60 sq. miles).

Initial reconnaissance soil survey of some 98,300 ha (384 sq. miles) in the Duck Mountain Forest Reserve (R29) completes the soil coverage for this 1,284 sq. mile area of western Manitoba. Final field correlation and sampling remain to be completed. In addition, correlation and upgrading of the reconnaissance level (1:125,000 scale) soil mapping for some 50,000 ha (195 sq. miles) in the Swan Lake (R18) project were completed. Sampling and characterization of the important agricultural soils will be completed in 1988.

Soil mapping and characterization of benchmark sites to assess impact of acid rain continued in the Duck Mountain and the Pointe du Bois area and detailed sampling and soil characterization was conducted to provide a heavy metal assay of 3 forest sites in northern Manitoba.

Soil reports have been published for five soil survey areas (see list of publications). Soil reports for the R.M. of South Norfolk (D74) and the Whitemouth Peatland (D71) are in press and will be available within the current fiscal year. Reports and maps for the R.M. of Victoria (D75), Villages of Hamiota, Elkhorn, Strathclair, Rapid City, Newdale, Birtle and Shoal Lake (D65), St. Eustache, Springstein, Perimeter Strip, Brunkild, La Salle River (D67), Snow Lake Townsite (D69) and Elk Island-Victoria Beach (D73) have been completed to publication stage.

SOIL CHARACTERIZATION AND MONITORING STUDIES

Research into groundwater-soil-salinity relations is on-going in the Warren-Marquette area. Data on soil pH, organic matter content and selected heavy metals are being evaluated in terms of the 1:1,000,000 scale generalized soil landscape map coverage for Agro-Manitoba. Monitoring of water tables and soil temperatures continues on selected

benchmark sites throughout southern and central portions of the province.

LAND EVALUATION

A land productivity indexing model (PIXMOD) has been applied to a relational data base integrating soil, climate and land management data for the 1:1 million scale Generalized Soil Landscape Map coverage for Agro-Manitoba. Probability analysis of obtaining various yields of wheat have been derived for 21 soil series in 27 polygons on the generalized soil landscape map. Completion of this analysis for the remaining agricultural soils is underway.

SOIL RESOURCE DATA MANAGEMENT SYSTEM

The soil survey is committed to implementation of an ARC/INFO based geographic information system for managing cartographic and related soil and landscape data. To take advantage of this powerful analytical and output capability, soil survey staff are concentrating on loading existing soil data into the INFO file structure. This work is currently being accelerated with support from an ERDA funded cooperative project with the Department of Soil Science at the University of Manitoba.

PUBLICATIONS

Soil Reports

Langaan, M.N. 1986. Soils of the Rural Municipality of Lorne. Report No. D70. Canada-Manitoba Soil Survey.

Michalyna, W. and W. Fraser. 1987. Soils of the Shellmouth Reservoir North. Report No. D63. Canada-Manitoba Soil Survey.

Mills, G.F. and I.G. Podolsky. 1987. Soils of the Swan River Townsite Area D37. Canada-Manitoba Soil Survey.

Podolsky, Glenn. 1986. Soils of the Towns of Fraserwood, Inwood, Komarno and a Strip of the Lake Manitoba Shoreline Report D57. Canada-Manitoba Soil Survey.

Podolsky, Glenn. 1987. Soils of South Assiniboine River. Report No. D64. Canada-Manitoba Soil Survey.

Other Publications

Participation by soil survey staff in various seminars, workshops and symposia resulted in the following publications:

Eilers, R.G. 1987. Summary of Some Soil-Hydrology Studies in Manitoba. Invited seminar to staff and students, Dept. of Soil Science, North Dakota State University, Fargo, N.D., Feb. 20/87.

Eilers, R.G. 1987. A "Revised" Methodology for Assessing Land Suitability for Irrigation, Canadian Water Resources Association, 40th Annual Conference, June 15-18, 1987, Winnipeg, Manitoba.

Eilers, R.G. 1987. Hydrological Interpretations of Soil Survey Data. Proc. of the "Dryland Salinity Control" Workshop, Calgary, Alberta, Feb. 24-25, 1987.

Eilers, R.G. 1987. Soil Management Problems in the Hadashville-Whitemouth Area. Report to Manitoba Dept. of Agriculture.

Mills, G.F., H. Veldhuis and R.G. Eilers. 1987. Thermal and Moisture Regime Characteristics of a Veneer Bog in North Central Manitoba. Proc. Symposium '87 Wetlands Peatlands, Edmonton, Aug. 23-27, 1987.

Ross, G.J., R.G. Eilers and K.C. Ivarson. 1987. Influence of Acid Sulfate Weathering on Chemical and Mineralogical Properties of an Acid Sulfate Soil of Manitoba. Can. J. Soil Sci. (in press).

SUMMARY OF SOIL SURVEY COVERAGE FOR MANITOBA
JANUARY, 1988

Map Project Designation	Name (Soil Report No.)	Report[1] Status	Area in Hectares	Map Unit[2] Description	Survey[3] Intensity Level	Map Scale	Map[4] Base	Land Evaluation[5] & Interpretations
Detailed Studies and Surveys								
D1	Pasquia (No. 11)	Pub. 1960	57 200	a,b,d	3	1:63,360	Color	A
D2	Glenlea Research Station	Int. 1963	541	a,b	1	1:7,920	Photo	A
D3	Morden Experimental Farm	Int. 1961	256	a,b	1	1:12,000	Photo	A
D4	Onanole	Pub. 1968	768	a,b	1	1:7,920	Photo	U
D5	York Factory Area	Int. 1969	768	a	3	1:63,360	B&W	
D6	McCreary Tile Drain Project	Int. 1971	64	a,b	1	1:5,000	B&W	A
D7	Brandon Experimental Farm	Int. 1985	768	a,b	1	1:7,920	Photo	A
D8	Portage Potato Farm	Int. 1972	480	a,b	1	1:4,800	Photo	A
D9	Portage la Prairie (No. 17)	Pub. 1972	113 200	a,b,c	2	1:20,000	Photo	A,I,E,U,R
D10	Morden-Winkler (No. 18)	Pub. 1973	71 424	a,b,c	2	1:20,000	Photo	A,I,E,U,R
D11	Deep Lake	Int. 1975	1 400	a,b	1	1:6,000	B&W	R
D12	Thompson Environmental Study	Int. 1976	32	a,b	1	1:1,000	B&W	
D13	Organic Soil Study of Alexander L.G.D.	Int. 1975	29 456	a,b	3	1:63,360	B&W	A
D14	Winnipeg Region	Pub. 1975	306 000	a,b,c	2	1:20,000	Photo	A,E,U,R
D15	Brandon Region	Pub. 1976	73 250	a,b,c	2	1:20,000	Photo	A,E,U,R
D16	Boissevain-Melita (No. 20)	Pub. 1978	262 912	a,b,c	2	1:20,000	Photo	A,I,E,U,R
D17	Roseau River	Pub. 1977	45 200	a,b	3	1:20,000	B&W	A
D18	Orr Lake	Int. 1977	20	a,b	1	1:1,000	B&W	
D19	Pelican-Rock Lake	Pub. 1983	14 080	a,b	2	1:20,000	Photo	A,E,R,I
D20	West Portage-MacGregor	Pub. 1982	124 866	a,b	2	1:20,000	Photo	A,I,E,R
D21	Minnewasta	Pub. 1978	2 560	a,b	2	1:20,000	Photo	A,E,R,I
D22	Killarney	Pub. 1979	4 600	a,b	2	1:20,000	Photo	A,E,R,I
D23	Matlock-Gimli-Riverton	Pub. 1981	18 400	a,b	2	1:20,000	Photo	A,E,R,I
D24	Glenboro	Pub. 1979	5 960	a,b	2	1:20,000	Photo	A,E,R,I
D25	Sandy Lake	Pub. 1980	1 720	a,b	2	1:20,000	Photo	A,E,R,I
D26	Brokenhead	Pub. 1979	10 813	a,b	2	1:20,000	Photo	A,E,R,I,U
D27	Rockwood	Pub. 1980	12 928	a,b	2	1:20,000	Photo	A,E,R,I,U
D28	Oak Lake	Pub. 1979	1 293	a,b	2	1:20,000	Photo	A,I
D29	Bird River	Pub. 1980	2 560	a,b	2	1:20,000	Photo	A,E,R
D30	North Shore Lac du Bonnet	Pub. 1980	2 400	a,b	2	1:20,000	Photo	A,E,R
D31	Grindstone Point	Pub. 1979	8 223	a,b	2	1:20,000	Photo	A,E,R

SUMMARY OF SOIL SURVEY COVERAGE FOR MANITOBA (continued)
JANUARY, 1988

Map Project Designation	Name (Soil Report No.)	Report[1] Status	Area in Hectares	Map Unit[2] Description	Survey[3] Intensity Level	Map Scale	Map[4] Base	Land Evaluation[5] & Interpretations
D32	Paint Lake	Int. 1980	2 880	a,b	2	1:10,000	Photo	A,E,R
D33	Cranberry Portage	Int. 1980	80	a,b	1	1:5,000	Photo	A,E,R
D34	Dauphin	Pub. 1981	8 005	a,b	2	1:20,000	Photo	A,E,R,I
D35	South Riding Mtn.	Pre.	23 488	a,b	2	1:20,000	Photo	A,E,R
D36	West Interlake	Pub. 1981	10 036	a,b	2	1:20,000	Photo	A,E,I,R
D37	Swan R. Townsite	Pub. 1987	7 680	a,b	2	1:20,000	Photo	A,E,R,I
D38	Hadashville-organic	Pub. 1981	6 475	a,b	3	1:40,000	Photo	A,E,I,R
D40	Falcon L-Brereton L	Pre.	39 311	a,b	2	1:20,000	Photo	A,E,R
D41	Quesnel Lake-North Shore Winnipeg River	Pre.	6 009	a,b	2	1:20,000	Photo	A,E,R
D42	Duck Mountain	Pub. 1982	3 036	a,b	2	1:20,000	Photo	A,E,R
D43	Spruce Woods	Pre.	26 300	e	3	1:40,000	Photo	A,E,R
D45	Pine Creek	Pub. 1983	1 942	a,b	2	1:20,000	Photo	A,E,R,I
D46	Arborg-Riverton	Pub. 1982	2 590	a,b	2	1:20,000	Photo	A,E,R,I
D47	Roblin	Pub. 1983	4 096	a,b	2	1:20,000	Photo	A,E,R,I
D48	Flin Flon	Pre.	4 600	a,b	2	1:20,000	Photo	A,E,R
D49	St. Anne-La Broquerie, Part of L.D.G. Stuartburn	Pub. 1985	105 280	a,b	3	1:50,000	B&W	A,E,R,I
D50	City of Brandon	Pub. 1984	2 980	a,b	2	1:20,000	Photo	A,E,R,I
D51	Westbourne	Pub. 1985	51,456	a,b	2	1:20,000	Photo	A,E,R,I
D52	Notre Dame, Rathwell, Treherne Townsites	Int. 1984	6 144	a,b	2	1:20,000	Photo	A,E,R,I
D53	Altona, Emerson, Gretna, Ile des Chenes, Landmark, Letellier, Rosenort, St. Jean Townsites	Pub. 1984	14 080	a,b	2	1:20,000	Photo	A,E,R,I
D54	Russell, Binscarth-Townsites	Pub. 1984	3 791	a,b	2	1:20,000	Photo	A,E,R,I
D55	St. Rose Du Lac-Townsite	Pub. 1985	1 536	a,b	2	1:20,000	Photo	A,E,R,I
D56	Souris, Wawanesa, Virden, Townsites	Pub. 1986	6 400	a,b	2	1:20,000	Photo	A,E,R,I
D57	Fraserwood, Inwood, Konarno Townsites, Lake Man. Shoreline	Pub. 1987	1 856	a,b	2	1:20,000	Photo	A,E,R,I
D58	Hallboro, Minnedosa-Townsites	Pub. 1984	4 544	a,b	2	1:20,000	Photo	A,E,R,I
D59	Beaudry Park	Int. 1986	640	a,b	2	1:20,000	Photo	A,E,R
D60	Rural Municipalities of Dufferin, Grey, Roland, Thompson and Stanley	Pre.	325 000	a,b	2	1:20,000	Photo	A,E,R,I
D61	Meditation Lake	Pre.	3 072	a,b	2	1:20,000	Photo	A,E,R
D62	Wanipigow Lake	Pre.	8 960	a,b	2	1:20,000	Photo	A,E,R

SUMMARY OF SOIL SURVEY COVERAGE FOR MANITOBA (continued)
JANUARY, 1988

Map Project Designation	Name (Soil Report No.)	Report[1] Status	Area in Hectares	Map Unit[2] Description	Survey[3] Intensity Level	Map Scale	Map[4] Base	Land Evaluation[5] & Interpretations
D63	Shellmouth Resevoir-N	Pub. 1987	4 650	a,b	2	1:20,000	Photo	A,E,R,I
D64	Assiniboine River	Pub. 1987	4 095	a,b	2	1:20,000	Photo	A,E,R,I
D65	Villages of Hamiota,Elkhorn, Strathclair, Rapid City, Newdale, Birtle, Shoal Lake	Pre.	6 204	a,b	2	1:20,000	Photo	A,E,R,I
D66	Benito-Durban	Pre.	18 432	a,b	2	1:20,000	Photo	A,E,R,I
D67	St. Eustache, Springstein, Perimeter Strip, Brunkild, La Salle R.	Pre.	6 200	a,b	2	1:20,000	Photo	A,E,R,I
D68	Spruce Point Mine Area	Pub. 1987	450	a,b	2	1:10,000	Photo	E,R
D69	Snow Lake	Pre.	2 333	A,B	2	1:20,000	Photo	A,E,R,I
D70	Lorne	Pub. 1987	93 240		3,2	1:50,000	B&W,Photo	A,E,R,I
D71	Whitemouth Peatland	Pre.	10 359	a,b	3	1:50,000	Photo	A,E,R,I
D72	Woodlands R.M.	Pre.	9 728	a,b	3	1:50,000	Photo	A,E,R,I
D73	Elk Island-Victoria Beach	Data	2 592	a,b	2	1:20,000	Photo	A,E,R,I
D74	S. Norfolk R.M.	Int.	70 912	a,b	2	1:20,000	Photo	A,E,R,I
D75	Victoria R.M.	Pre.	67 328	a,b	2	1:20,000	Photo	A,E,R,I
D76	Rhineland (con't.)	Data	13 985	a,b	2	1:20,000	Photo	A,E,R,I
D77	Pembina (con't.)	Data	27 972	a,b	3	1:50,000	B&W	A,E,R,I
D78	Springfield*	Data	98 270	a,b	2	1:20,000	Photo	A,E,R,I
D79	Rockwood R.M.*	Pre.	116 550	a,c	4	1:125,000	B&W	A,E,R,I
D80	N. Norfolk R.M.	Data	110 592	a,b	2	1:20,000	Photo	A,E,R,I
*	Upgrade of Data Base							
Reconnaissance Surveys								
R1	South Western (No. 3)	Pub. 1940	709 600	d	3	1:125,000	B&W	A
R2	South Central (No. 4)	Pub. 1943	967 600	d	3	1:125,000	B&W	A
R3	Winnipeg and Morris (No. 5)	Pub. 1953	1 419 200	d	3	1:125,000	Color	A
R4	Rossburn and Virden (No. 6)	Pub. 1956	1 372 400	d	3	1:125,000	Color	A
R5	Carberry (No. 7)	Pub. 1957	967 600	d	3	1:125,000	Color	A
R6	West-Lake (No. 8)	Pub. 1958	592 800	d	3	1:125,000	Color	A
R7	Grandview (No. 9)	Pub. 1957	689 200	d	3	1:125,000	Color	A
R8	Nelson River Basin (No. 10)	Pub. 1973	224 000	b	3	1:100,000	Color	A
R9	Fisher and Teulon (No. 12)	Pub. 1961	949 200	a,c	3	1:100,000	Color	A
R10	Swan River (No. 13)	Pub. 1962	316 000	a,c	3	1:125,000	Color	A
R11	South Eastern (No. 14)	Pub. 1964	749 200	a,c	3	1:125,000	Color	A,F
R12	Lac du Bonnet (No. 15)	Pub. 1967	764 800	a,c	3	1:125,000	Color	A,F,R
R13	Grahamdale (No. 16)	Pub. 1971	764 800	a,b	3	1:125,000	Color	A,F,U,R,E
R14	Red Rose-Washow Bay (No. 19)	Pub. 1975	704 400	a,b	3	1:125,000	Color	A,F
R15	Boissevain-Melita (No. 20)	Pub. 1978	299 520	a,b	2	1:40,000	Photo	A,I,E
R16	Ste. Rose (No. 21)	Pub. 1981	676 705	a,b	3	1:125,000	Color	A,I,R,E,F
R17	Waterhen (No. 23)	Pub. 1985	949 600	a,b	4	1:125,000	B&W	A,I,R,E,F
R18	Swan Lake	Data	599 200	a,b	3,4	1:125,000	B&W	A
R19	The Pas (No. 22)	Pub. 1982	791 700	a,b	4	1:125,000	Color	A,I,E,R,F
R20	Grand Rapids	Pre.	675 031	a,b	4	1:125,000	B&W	A

SUMMARY OF SOIL SURVEY COVERAGE FOR MANITOBA (continued)
JANUARY, 1988

Map Project Designation	Name (Soil Report No.)	Report[1] Status	Area in Hectares	Map Unit[2] Description	Survey[3] Intensity Level	Map Scale	Map[4] Base	Land Evaluation[5] & Interpretations
R21	Cormorant	Int. 1975	920 000	a,b	4	1:125,000	B&W	A
R22	Wekusko	Pre.	1 400 000	a,b	4	1:125,000	B&W	A
R23	Pointe du Bois	Pre.	740 000	a,b				
R25	Red Deer Lake	Pub. 1966	34 860	a,b	2	1:31,680	Photo	A
R26	Cross Lake and Norway House	Pre.	615 200	a,b	4	1:125,000	B&W	A
R28	Pasquia Lake	Pub. 1984	2 330	a,b	3	1:50,000	B&W	A,E
R29	Duck Mountain For. Reser.	Data	363 264	a,b,c	4	1:125,000	B&W	A,F,E,R,I

SUMMARY OF SOIL SURVEY COVERAGE FOR MANITOBA (continued)
JANUARY, 1988

Map Project Designation	Name (Soil Report No.)	Report[1] Status	Area in Hectares	Map Unit[2] Description	Survey[3] Intensity Level	Map Scale	Map[4] Base	Land Evaluation[5] & Interpretations
Biophysical and Exploratory Surveys								
B1	Lake Winnipeg, Churchill & Nelson Rivers	Pub. 1973	3 600 000	e	4	1:250,000 1:50,000	B&W	
B2	Churchill Transportation Corridor	Data 1974	179 000	f	4	1:125,000	B&W	
B3	54C Hayes River	Int. 1976	1 370 300	f	4	1:125,000	B&W	
B4	54D Kettle Rapids	Int. 1976	1 370 300	f	4	1:125,000	B&W	
B5	52M Carrol Lake	Int. 1977	634 000	f	4	1:125,000	B&W	
B5	62P Hecla	Int. 1977	466 200	f	4	1:125,000	B&W	
B6	53D Deer Lake	Int. 1978	629 700	f	4	1:125,000	B&W	
B6	63A Berens River	Int. 1979	848 500	f	4	1:125,000	B&W	
B7	53M Knee Lake	Int. 1978	1 405 900	f	4	1:125,000	B&W	
B8	53L Oxford House	Int. 1978	1 441 100	f	4	1:125,000	B&W	
B8	63H Norway House	Data	540 800	f	4	1:125,000	B&W	
B9	SE 1/4 64A Split Lake	Int. 1979	342 400	f	4	1:125,000	B&W	
B9	63P Sipiwesk	Int. 1979	1 405 900	f	4	1:125,000	B&W	
B10	53E Island Lake	Pre.	1 286 900	f	4	1:125,000	MSS	
B11	63H Norway House	Data				1:125,000	B&W	
E1	Surface Deposits & Soils of Northern Manitoba	Int. 1963		g	5	1:1,267,000	B&W	
E2	Exploratory Terrain Study of Northern Manitoba and Southern Keewatin, N.W.T.	Int. 1974		g	5	1:1,000,000	B&W	

1. Report Status
   Pub.-Published Report and Map
   Int.-Interim Report and Map Available
   Pre.-Preliminary Map and Legend Available
   Data-Field Data Available Only

2. Map Unit Descriptions Code
   a-single series and phases
   b-series complexes defined as to proportion
   c-series complexes undefined as to proportion
   d-associations
   e-biophysical units (materials and physiography)
   f-biophysical units (associations & complexes of associations)
   g-regional and local physiographic units

3.Survey Intensity Levels

Code	Name	Scale	Minimum Size Delineation(ha)	Inspection Density (Approx. range)
1	Very detailed	>1:12,000	<1.5	>1 per 3 ha
2	Detailed	1:12,000 to 1:40,000	1.5-16	1 per 3 to 50 ha
3	Semi-detailed	1:40,000 to 1:125,000	16 to 256	1 per 10 to 1 000 ha
4	Reconnaissance	1:125,000 to 1:250,000	256 to 625	1 per 100 to 110 000 ha
5	Exploratory	1:250,000 to 1:1,000,000	625 to 110 000	1 per 300 to 500 000 ha

4.Published Map Base Code

Photo-Photomosaic
B&W -Black and white line
Color-Colored line

5.Interpretations Code

A-Agriculture Capability
E-Engineering
F-Forestry
I-Irrigation Suitability
U-Urban Planning and Community Development
R-Recreation

TOTAL HECTARAGE COVERED

	1987	To Date
Initial Reconnaissance	129,984	19,258,210
Initial Detailed survey	779	18,793
Detailed Resurvey	88,576	3,283,465
Biophysical Survey	---	12,521,000

Published Reports, Maps, Interim Reports, available at a cost of $2.00 per copy (except for D20) from:

Queen's Printer,
Publications Branch,
Manitoba Archives Bldg.,
200 Vaughan St.,
Winnipeg, Manitoba R3C 1T5
Phone:945-3103

Detailed Surveys of Winnipeg Region and Brandon Region available at a cost of $6.00 each from:

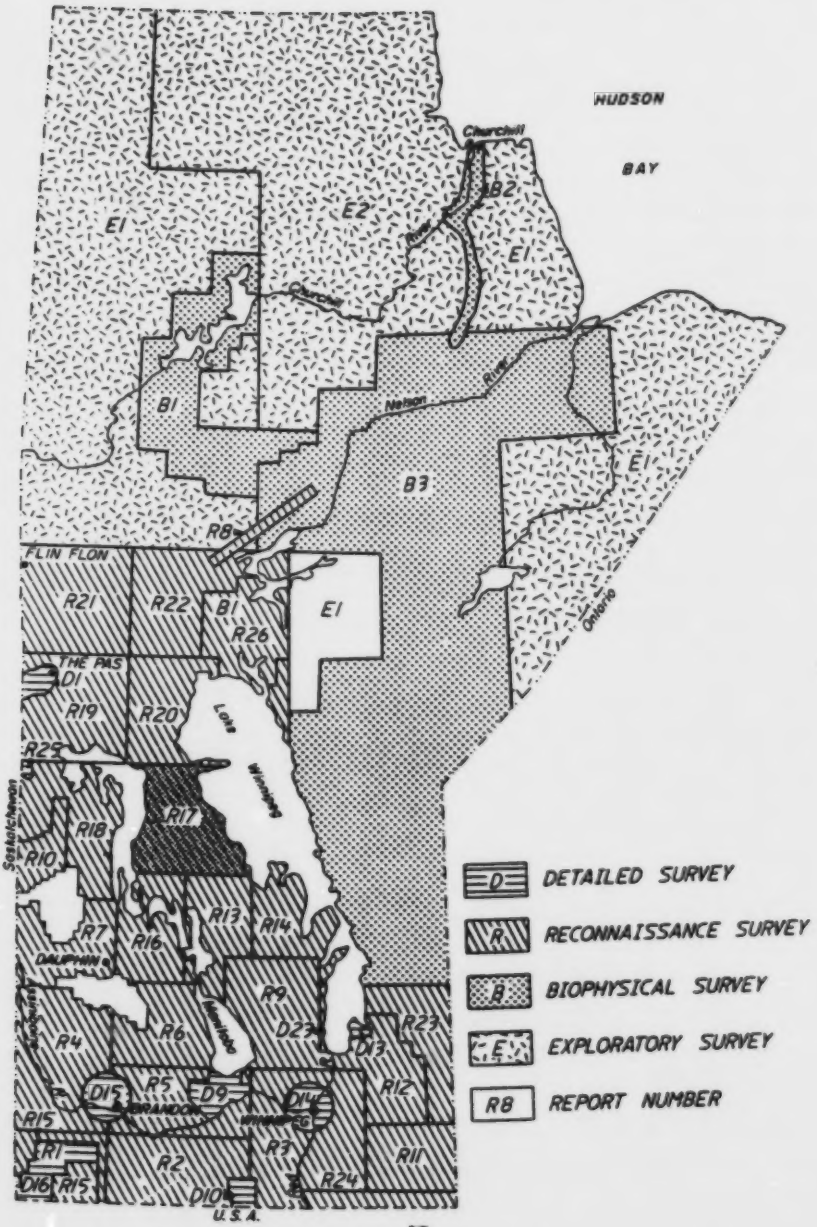
Municipal Planning Branch
Manitoba Dept. of Municipal Affairs
1418-405 Broadway Ave.,
Winnipeg, Man., R3C 3L6
Phone: 945-2150

Biophysical Land Classification Maps and Reports available at a cost of $3.50 each from:

Surveys and Mapping Branch
Century Industrial Branch
989 Century Plaza
Winnipeg, Man., R3H 0W4
Phone: 945-6666

Preliminary Map and other field data available from:

Canada-Manitoba Soil Survey Office,
Rm. 362 Ellis Bldg., University of Manitoba
Winnipeg, Man., R3T 2N2
Phone: 474-6115 or 474-6118



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LOCATION OF RECONNAISSANCE AND BIOPHYSICAL SURVEYS

AUTOMATED MAPPING FOR AGRICULTURE

An application of AM/FM/GIS systems for enhancement of land use studies and land planning activities.

WHY AUTOMATED MAPPING?

The development of computer mapping techniques has provided planners involved in land use and land related studies with an opportunity to improve the quality of their work in a shorter time period. The use of computer generated maps and data bases, and the ability to inter-relate the information through a GIS system has opened new passabilities. The ability to use and modify stored information and to analyses it according to your own requirements is a major advancement.

In manual systems the drafting of base maps and overlays is a very labor intensive process. At the present time, with financial and personnel constraints, in both government and in business, it is difficult to have sufficient time or staff to properly complete a detailed land use plan. However,an opportunity to substitute computer hardware and software for personnel, appears to exist.

In a manual system, there is a limit in the number of alternative scenarios that can be evaluated when conducting a land use study. The time required to draft and compare different maps and to define the problem areas or conflict sites is to great for most cases. The ability to identify conflict, or problem areas was dependent on the experience of the individual planner. If one person developed special skills in analysis, it is difficult to pass this special knowledge on to other workers. Frequently, this skill were lost when the individual moved on to other work. If this same person had been working on a computer program were the knowledge become part of the program, then it could be retained for future planners to build upon.

The capability to relate several types of information, such as maps and data which are geographically oriented, is essential to the evaluation process in making good quality land use decisions. Also, the testing of alternative land use scenarios, can improve the quality of the final recommendation or map and report produced.

The capacity to overlay several maps is a very useful characteristic. The computer can analysis this quantity of data, however a person would have some difficulty in mentally processing and sorting that much data.

A key component in the computer use, is access to maps and data file which have been created and stored in preparation for use by any number of persons or agencies. The attribute maps are overlayed on base maps and the size adjusted to your needs. This gives you the power to create the product require to display or illustrate your message.

COMPONENTS OF A AUTOMATED MAPPING SYSTEM

ATTRIBUTE MANAGEMENT [AM] is any of the maps of the physical features, such as soils, vegetative cover, topography, roads, ditches, telephone lines and hydro lines. Each has a specific location on the earths surface and can be defined and located on a map by defining it's coordinates. By extending this process to other information, it is possible to overlay this material and create a new map.

FILE MANAGEMENT [FM] is the use and manipulation of information stored in a data base format, but is related to a specific location. Data, such as crop records, land ownership, soil analysis, soil test results, climatic records, demographic data, can be inter-related with the map information.

GEOGRAPHIC INFORMATION SYSTEMS [BASE MAP] is the Geodetic Reference Framework which ties all the information together. This allows the various cadastral maps and data bases to be interrelated and analyzed.

The AM/FM/GIS system will present the information on any size map you desire. This allows a person to study and present their information in a format of their choice. The ability to overlay information in is one of the most valuable assets of this computer system. The analysis can include a quantitative statement as well as a visual presentation. Although this was done in the past studies, it was a time consuming and labor intensive process.

THE DEVELOPMENT OF COMPUTERS MAPPING SYSTEMS

The development of computer technology is relatively recent, although is seems to have been around for years. In reality, it is less then five years since we have had access to many of the mapping applications. In fact, the technology is coming in faster then most of use can keep up with and we suffer from "Future Shock".

Although the technology has been around for several years, it was primarily on mainframe computer systems which were not available to most people. Recent developments in micro computers and software programs have made it possible to acquire a hardware and software system for individual offices which are involved in land use planning.

A MICRO COMPUTER APPLICATION PROGRAM

One micro computer based program created by TYDAC® Technologies Inc. called "SPATIAL ANALYSIS SYSTEMS" shows promise of being a very useful tool in land use planning. The program will run on a micro computer with 640k and a 30mb hard disk. The graphics card and printer are of a specific type to permit display of the color maps and

plans. The system can overlay up to fifteen maps and calculate the area of specific sites. This permits the testing of different scenarios at the touch of a button [or two].

LAND INFORMATION NETWORK for MANITOBA

The Government of Manitoba has been investigating the benefits of establishing a multipurpose land information network for Manitoba. The interest was renewed several years ago when a utilities company proposed that they would like to create an AM/FM/GIS system for their own use. After examination of the proposal it was suggested that an integrated system for the province should be developed.

This lead to the creation of the LINAC committee which has been wrestling with the problems of how to start such a system.

A general model of the network system is as follows;

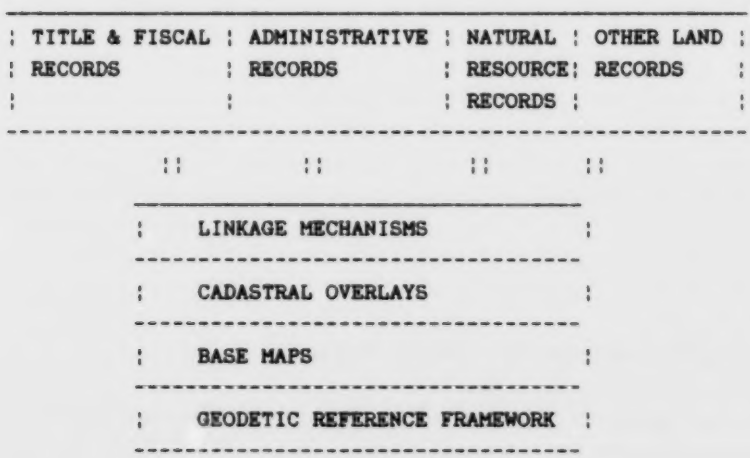

Figure 1

This model displays the general concept of interaction between the data base files and the cadastral maps.

BASE MAPS

The significance of a multipurpose network include the concept of shared base maps. There would be one agencies preparing the Geodetic reference network and preparing the base maps which would be used by other agencies. this process would eliminate much unnecessary duplication. Since the costs associated with this work are considerable, benefits of cooperation are correspondingly large. The apparent organization to do this work is the Surveys Branch of the Department of Natural Resources.

ATTRIBUTE MAPS

Correspondingly, Telephone System would keep track of telephone lines, Manitoba Hydro the power lines, Land Titles Office the records of ownership and the Soil Survey the information on soil pedology.

Agriculture will be a user of information, however their is two areas where information is created. These are Soils data and crop yield data. There is a need to look to these information sources and do our share by making them available as part of the information pool.

DATA EXCHANGE

The needs of this system is to create the framework under which the information can be exchanged by electronic means. this means compatible or translatable computer language. This is not an easy task to complete, however the benefits which can be derived through an integrated system, particularly for a user department such as Agriculture, are significant.

This is only a few comments on this subject, however, I hope that it is sufficient to perk your interest and to encourage you to examine the subject in more detail at a future date.

C.L.I. Soil Capability Classification - Its Practical Application

A. O. Toews - Manitoba Agriculture

Sterling Lyon stated: "In years to come the CLI will be seen to be as important to Canadian development as the building of the CPR." This prediction has already, to a considerable degree, proved correct with the extensive use of the Canada Land Inventory System in all areas of land resource allocation.

However, there have been some misconceptions about the system and it might be useful to arrive at a proper perspective of CLI by quoting a few authors who have previously presented papers at Manitoba Soil Science Meetings and from publications prepared by the Lands Directorate.

The problem lies specifically in USERS attempting to use the system for SITE SPECIFIC evaluation and management of individual parcels of land.

In a publication titled "CLI In Perspective" by W.E. Rees, March 1977 he states as follows: "The need for the Canada Land Inventory evolved as a result of increasing regional economic disparity, wide-spread improper land use conflicts in all of the provinces. The overall goal of the CLI was to facilitate the orderly adjustment from inappropriate uses of land to more rational ones reflecting the transition of the national economy from a rural-agricultural to an urban-industrial base."

Further, in listing the objectives for each resource sector he states as follows for Agriculture: "The objective of the agricultural land inventory was to provide a soils and climate classification system useful to planners in the identification of the full range of highly productive to sub-marginal agricultural lands. Such data would be useful in determining areas of potential future agricultural activity, in facilitating the consolidation of sub-marginal farming operations into viable units, and in delineating areas where urban-industrial land uses might occur with minimal impact on agricultural production."

M.C. McKay in a paper titled "The Canada Land Inventory" reported on its progress at the 1968 Soil Science Meeting. The

purpose of the inventory had already at that time been clearly defined with his statement: "The inventory is designed primarily for planning rather than management. It is of a reconnaissance type which will provide information necessary to land resource development planning at the municipal, provincial and federal levels of government. It will not provide the detailed information required for management of individual parcels of land."

Criticisms have been voiced regarding this inventory questioning its value, particularly from the point of view of people dealing with actual management of resources.

A. Brian Ransom in a paper titled "Land Management and the Capability Gap" presented at the 1969 Soil Science Meeting focuses on this problem: "The object of this paper is to show that available land capability information is relevant to problems of resource allocation but is unsuitable for management purposes. ----- Such efforts can yield only limited success and a new system of gathering land capability information must be devised on the basis of there being a clear distinction between the needs of allocation and management....Canada Land Inventory maps and reports are of very limited use in the actual management of resources."

Richard C. Goulden in a paper titled "The Canada Land Inventory in Manitoba - An Appraisal"presented at the 1969 Soil Science Meeting sums up the dilemma of "would-be users" of the system: "In our naivety I am afraid we have misjudged the complexity of those resources over which we claim domain. The ironical fact, and one which is not appreciated by many, is that the supreme complexity of intensive land planning and management was not envisioned and probably would not be acknowledged today, had we not plunged in."

"It would appear from my obviously biased viewpoint that the Canada Land Inventory in Manitoba is basically accomplishing what it was set up to do."

Provincial Land Use Planning in Manitoba is governed by The Planning Act assented to June 19, 1975.

Provincial Land Use Policies were formulated shortly after and the revised document dated November, 1980 continues in force to the present day.

How the policies were formulated to take advantage of the CLI Inventory is apparent from various sections: e.g. "Areas should be preserved for a full range of agricultural activities where agriculture is in the dominant position on prime agricultural land and where agricultural activities are dominant on lower class lands and it is desirable to protect such activities."

"Prime Agricultural Land" means land defined as Classes 1, 2 and 3 soils by the agricultural land capability system of the Canada Land Inventory and interpreted as such by the Soil Survey, Manitoba Department of Agriculture. A land unit that has 60 percent or more prime land is considered to be prime agriculture in total.

Most of the special uses do not require prime agricultural lands and will therefore be encouraged to locate on lower class lands."

Apparent also is how these policies lend themselves to a broad interpretation of soil capabilities for agriculture.

Granted, as stated in one of the published reports put out by the Lands Directorate: "The C.L.I. system by itself simply does not account for the inter-relationships on trade-offs, environmental or social among the different resource sectors. Each capability map can therefore be described as an independent, static representation of an only more or less objective assessment of the land resource for a single purpose at a particular point in time. In short, the difficult task of interpretation and allocation in the light of contemporary socio-economic conditions is quite properly left to the user-planner."

To ensure that this difficult task of interpretation and allocation is not left to the dictates of the municipal planner alone, a section of the subdivision manual states as follows: "In the submission of comments with regard to a proposed subdivision, each department is responsible for the interpretation of those Provincial Land Use Policies or sections of development plans or basic planning statements as the case may be, which directly affect its area of jurisdiction. Such interpretation should provide full details regarding the department's position, implications arising therefrom and possible options for the applicant."

Municipal officials either as members on Council or members on District Planning Boards of course figure prominently in decisions on land use planning within areas under their jurisdiction. They are constantly exposed to comments of agencies of government which invariably include Canada Land Inventory information pertaining to either Agriculture, Forestry, Wildlife Habitat or Recreation.

The C.L.I. Soil Capability Classification is ideally suited to addressing Rural Land Use Area issues. These fall essentially into three main categories:

encroachment: loss of prime agricultural land through encroachment of rural non-farm residential development.

fragmentation: possible fragmentation of farm land into uneconomically sized parcels due to unplanned rural non-farm residential development.

land use conflict: conflict of interests between the farming community attempting to maintain productive and economical farming operations, and the rural non-farm community demanding both a higher level of services and a restriction on undesirable (nuisance) farming operations.

The Regional Land Resource Agrologists of Manitoba Agriculture along with the Land Utilization Section of Soils and Crops Branch providing co-ordination rely heavily on the C.L.I. Soil Capability for Agriculture, utilizing it for preparation of background agricultural reports and incorporation into Basic Planning Statements or Development Plans and in responding to subdivision applications. The latter are estimated to number 600 rural subdivision applications annually.

In preparation of background agricultural reports particular emphasis is placed on the C.L.I. Land Capability For Agriculture recommending that areas of Class 1, 2 and 3 prime agricultural lands and as well Class 4 lands be protected for agriculture. Land use alternatives are generally available that can minimize impacts on prime lands. In securing the preservation of agricultural land for the agricultural sector, proper conservation of this resource with protection from the ravages of wind and water erosion must continue

to be a major concern.

This use of the C.L.I. system demonstrates its importance for allocation purposes of the land resource recognizing at the same time that C.L.I. maps are generalized presentations at the "reconnaissance" level and not intended for site specific planning.

The Lands Directorate has produced and published a series of reports that present the methodology and other aspects of the CLI Programs.

As the inventory entered the final stage of completion the Lands Directorate also included studies that have effectively utilized the CLI data.

In a FORWARD to one of these studies referred to earlier R.J. McCormack, Director General-Lands Director encourages on-going assessments of the program and states as follows: "The Lands Directorate, the agency responsible for coordinating the federal participation in the Canada Land Inventory, encourages assessments of the use and utility of the data generated in the program. By so doing the directorate hopes to foster a better understanding of the data, the ends they may serve, and the problems encountered in their interpretation and application. Making such assessments available to Canada's resource planning community ensures an on-going evaluation of the CLI program itself a process from which all Canadians will benefit."

The system has been in use now for over a decade and an assessment of the use and utility of the data generated in the program may well be in order.

Users of the system are most cognizant of the problems encountered in the interpretation and application of the data.

It must be remembered that agricultural capability data were derived primarily from the extensive work done over the last fifty years by the federal and provincial soil survey staffs in soil surveys. Detailed soil surveys continue to be generated and they augment the soil capability data at our disposal.

Traditionally, soil survey serves the agricultural use of the land and the USER who requires SITE SPECIFIC information for a

comprehensive evaluation and for management purposes should be referring to soil survey information; preferably the detailed soil survey if it is available, rather than attempting to glean this information from the Canada Land Inventory.

The axiom "Don't fix it if it ain't broken" certainly holds true for the CLI system but it is also true that a reappraisal of the objectives, an upgrading of the data and some FINE TUNING generally is desirable.

HEAVY METAL CONTAMINATED SOILS AT THOMPSON, MANITOBA AND ITS EFFECTS ON THE GROWTH OF JACK PINE SEEDLINGS.

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Terrestrial Standards and Studies
Department of Environment and Workplace Safety and Health
Province of Manitoba

ABSTRACT

The growth of jack pine (Pinus banksiana Lamb.) seedlings reared in heavy metal contaminated surface organic soils (LFH) collected near the Inco Metals Company smelter at Thompson, Manitoba was investigated. Differences in physical development of seedlings were observed between sites over a twenty-four week greenhouse growing period.

It appears that toxic levels of metals, especially nickel and copper, are being absorbed by the seedling root tissue. Significant growth inhibition of seedling roots occurred in soils from sites within a 5 km radius of the smelter. There is concern that metal concentrations in the LFH medium may be contributing to a decline in the ability of this species to regenerate successfully.

1. INTRODUCTION

The Inco Metals Company located at Thompson, Manitoba operates an integrated nickel mining, milling, smelting and refining complex. Smelting operations began in 1961. Of primary environmental concern are the stack emissions of SO_2 and flue dust. The flue dust or particulate is comprised, in part, of the heavy metals nickel, copper, iron and zinc.

Other studies have documented that the physiolcgical development of plants can be significantly inhibited by the uptake of heavy metals (Malhotra and Khan 1981, Lozano and Morrison 1982).

A joint Federal/Provincial forest study initiated in 1977 showed that there is a gradient of heavy metal accumulation in the soils surrounding the smelter (Wotton and Hogan 1981).

2. METHODS

Samples of the LFH soil layer were collected in June, 1981 from each of twelve study site locations established by the joint Federal/Provincial study group. The LFH material was air dried and ground to a uniform texture. The LFH medium for each site was loaded into "styrobloc 20" styro containers. Seed, extracted from cones collected at the control site, was sown directly on the LFH soil in the styrobloc cells. The seeded styroblocs were placed on greenhouse benches and maintained for a period of twenty-four weeks.

After twenty-four weeks all seedlings were extracted from

each styrobloc cell and the mean shoot and root lengths were recorded for each site. Mean oven dry shoot and root mass for each site were also determined. Plant tissue and a pre-study sample of LFH from each site were analysed for total nickel, copper, iron, zinc, lead and cadmium.

3. RESULTS AND DISCUSSION

There are a number of metals in the smelter particulate emissions including Fe, Ni, Cu, Pb and Zn. Approximately 20 to 25% of the particulates are Fe but it is generally not toxic to vegetation at least not at the concentrations which are found in the Thompson soils. Pb and Zn on the other hand are potentially toxic but relatively small quantities have accumulated in the soil. This discussion will deal only with Ni and Cu. They comprise 5% and 2% of the particulate, respectively, are toxic to vegetation and have accumulated well above background concentrations at sites close to the smelter.

This report is restricted to the effects of heavy metals from the smelter emissions on root growth. Although there was a slight effect on shoot growth, the principal effect over the 24 week period was on root growth. Poor root development would be expected to have a detrimental effect on shoot growth over the longer term. The effects of other metals on root growth as well as the effects of metals on shoot growth are presented in a comprehensive report by Jones et al. 1984.

Figure 1 is a regression of Ni levels in LFH and Ni levels in seedling root tissue versus distance from the smelter. Concentrations of metals in LFH and in root tissue were significantly elevated within a 5 km radius of the smelter. Levels decreased gradually to background beyond that distance. There were very strong and highly significant inverse correlations with distance from the smelter. Ni levels in LFH and root tissue decreased with increasing distance from the smelter. The range of levels in LFH for Ni was 2200 µg/g at the closest site, 1.5 km southeast of the smelter, to 30 µg/g at the control, 66 km south of the smelter. A similar gradient existed for Ni in root tissue; 1600 µg/g at the closest site and 30 µg/g at the control.

Figure 2 presents regressions of Cu levels in LFH and Cu levels in seedling root tissue versus distance from the smelter. As with Ni, a gradient of decreasing Cu levels in LFH and root tissue with increasing distance from the smelter is evident. Cu levels in LFH ranged from 1200 µg/g to 10 µg/g and in root tissue from 350 µg/g to 20 µg/g.

Cu levels in LFH were about one half the level of Ni, the level of Cu in root tissue was about one fifth that of nickel. This indicates that Ni was taken up more readily than Cu. One reason for this may be that copper has been found to form a more stable chelate with organic molecules than nickel (Mellor and Maley, 1948 in Bowen, 1966).

Figure 3 is a regression of root growth and Ni levels in root

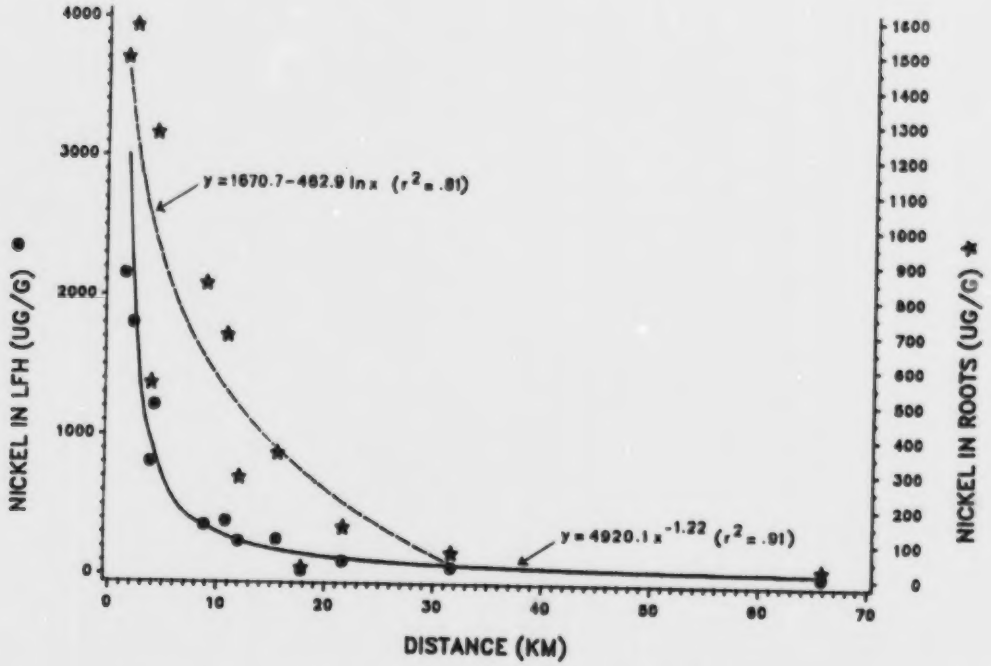

FIG.1: NICKEL IN SOIL AND JACK PINE ROOTS VS DISTANCE FROM THE INCO SMELTER,THOMPSON,MB.

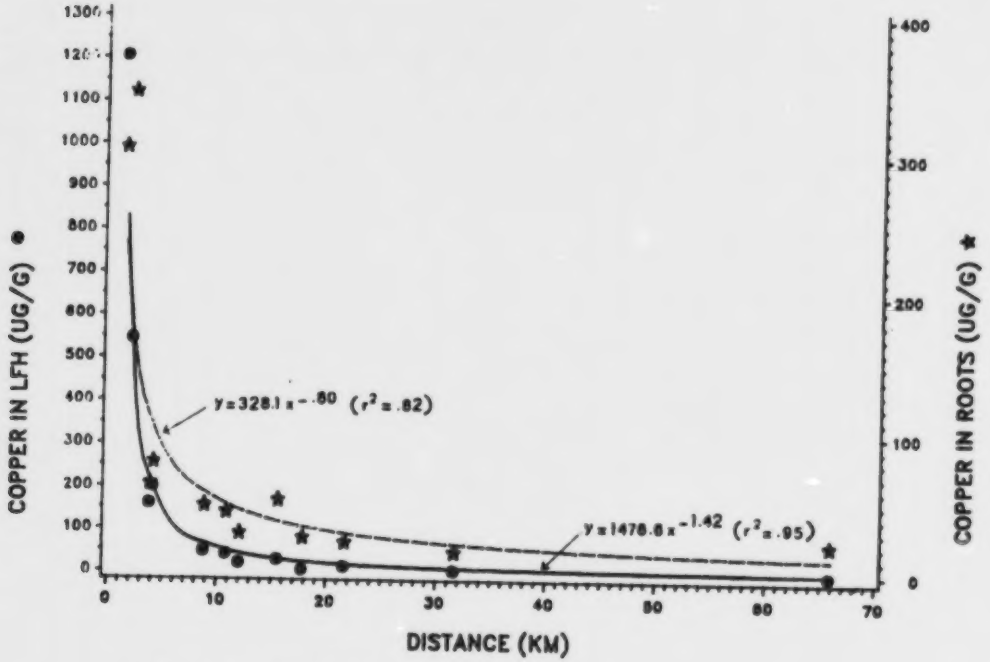

FIG.2: COPPER IN SOIL AND JACK PINE ROOTS VS DISTANCE FROM THE INCO SMELTER, THOMPSON, MB.

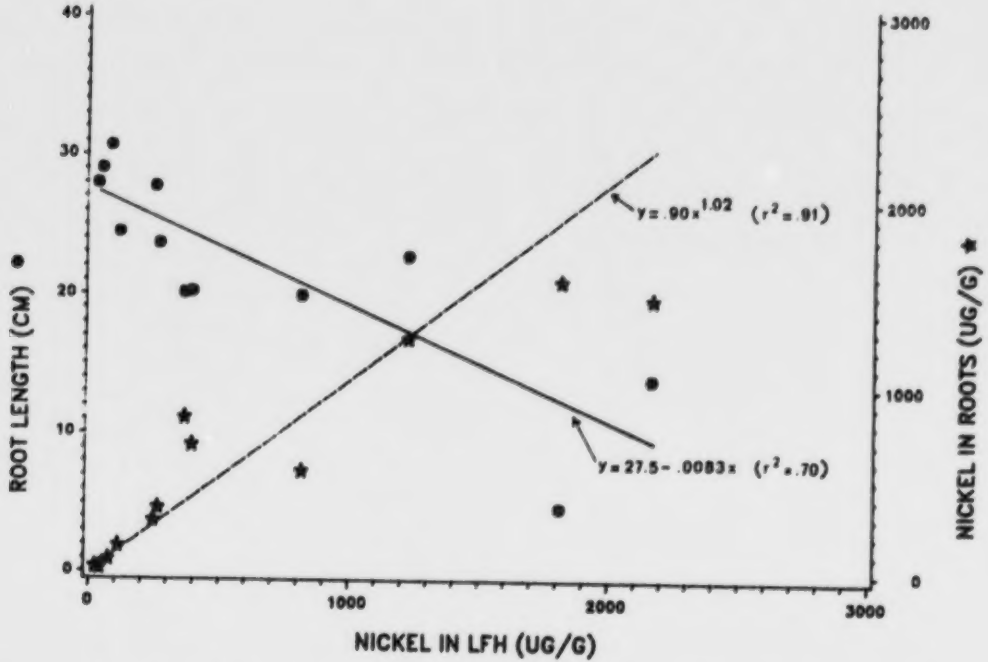

FIG.3: ROOT GROWTH AND NICKEL LEVEL IN ROOTS VS. NICKEL IN LFH

tissue versus Ni levels in LFH. It is evident that these metals were absorbed by the roots since uptake to the shoots, although not at the levels of those found in roots, was confirmed (Jones et al. 1984). A strong positive correlation exists between Ni levels in LFH and Ni levels in root tissue. Root growth was inversely correlated with metal levels in LFH. Root growth appears to be inhibited when the Ni concentration in the LFH was greater than 500 µg/g.

Figure 4 is a regresssion of root growth and Cu levels in root tissue versus Cu levels in LFH. The relationships are similar to those for Ni; Cu levels in roots were positively correlated with Cu levels in LFH. Root growth was also inversely correlated with Cu levels in LFH. Root growth seemed to be inhibited when the Ni and Cu concentrations in the LFH were greater than 500 µg/g and 200 µg/g, respectively.

Figure 5 illustrates the relationship between root growth and distance from the smelter. A positive and highly significant correlation exists. As distance increased root growth also increased. It would appear that significant root growth suppression occurred in LFH from within 5 km of the smelter but some growth suppression was also evident up to 10 km away from the smelter. The data show that sites closest to the smelter had the highest concentrations of metals in the LFH and in seedling root tissue, and also had the greatest degree of seedling growth inhibition. Root growth was virtually non-existent at sites within 3 km of the shelter and in some cases was limited only to the formation of rudimentary buds. Roots had very little lateral development, few or no root hairs and appeared blackened. This is typical of metal toxicity symptoms observed in other growth studies (Whitby and Hutchinson 1974, Malhotra and Blauel 1980). It is believed that two major factors may have been responsible for this seedling growth inhibition; elevated metal levels in the LFH causing ion exchange competition at the root surfaces and/or elevated metal levels in the root and shoot tissue causing direct or indirect toxic effects.

The effects of heavy metals on black spruce seedling growth was tested in a subsequent experiment and significant growth suppression was found in both root and shoot tissue.

A field trial is presently in progress to determine if seedling growth will be similarly suppressed when jack pine and black spruce seedlings are planted in heavy metal contaminated sites near Thompson, Manitoba.

5. CONCLUSIONS

1. Present levels of heavy metals, especially Ni and Cu in the LFH within a 5 km radius of the smelter are severely inhibiting the growth of jack pine seedlings.

2. There is a concern that the capability of jack pine to regenerate will be substantially reduced over a greater radius from the smelter as metal emissions continue to disperse and accumulate.

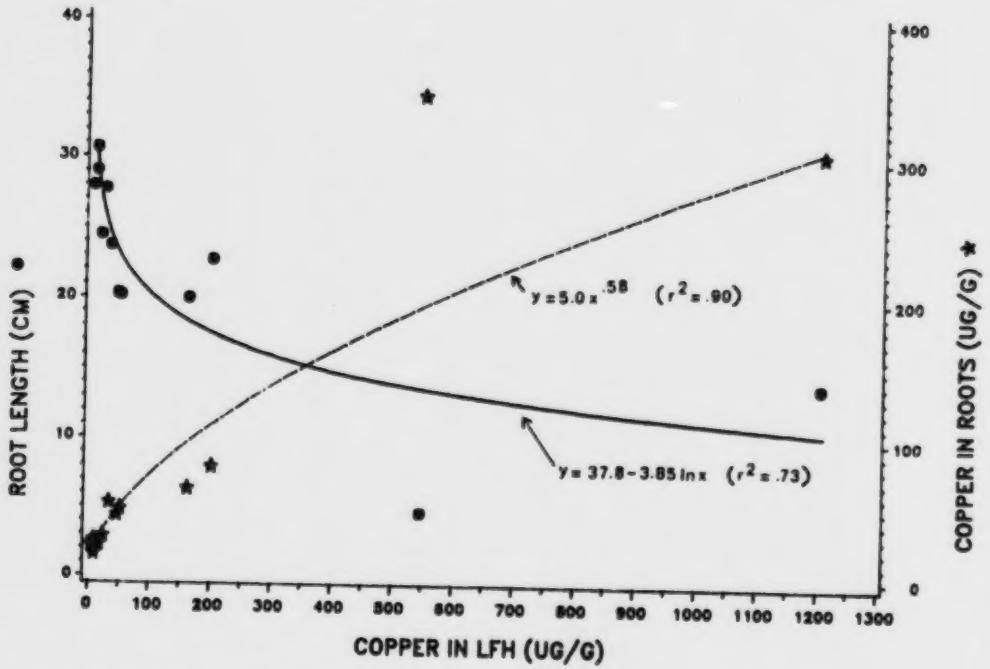

FIG. 4: ROOT GROWTH AND COPPER LEVEL IN ROOTS VS. COPPER IN LFH

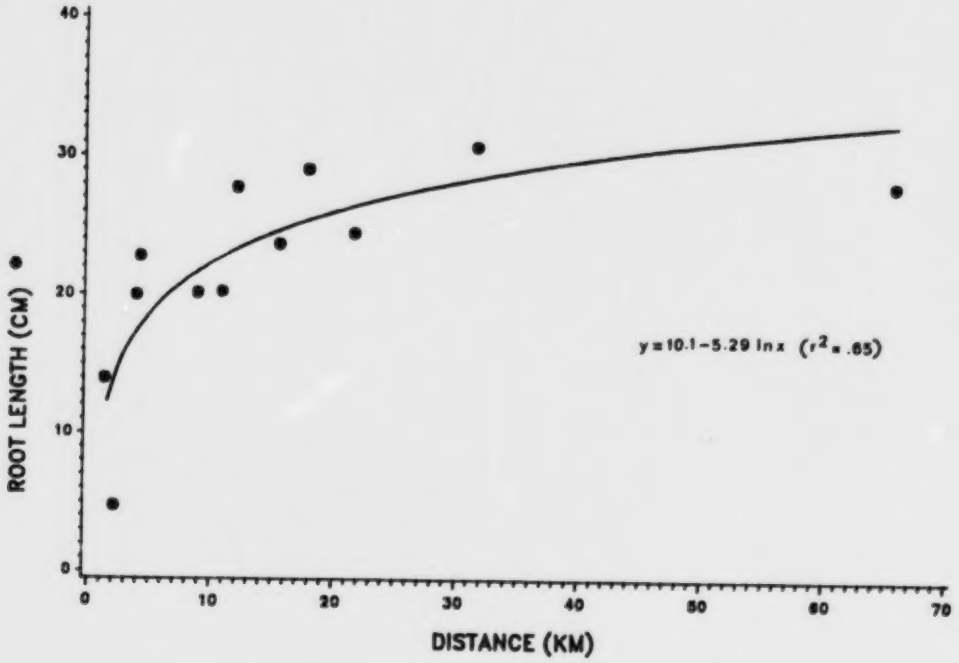

FIG.5: ROOT GROWTH VS DISTANCE
FROM THE INCO SMELTER, THOMPSON, MB.

REFERENCES

Bowen, H. J. M. 1966. Trace Elements in Biochemistry. Academic Press Londn and New Yord. 241pp

Jones, D. C., D. L. Wotton, D. B. McEachern and S. F. Phillips. 1984 The Growth of Jack Pine and Black Spruce Seedlings in Heavy Metal Contaminated Soils Collected Near The Inco Smelter at Thompson, Manitoba, Environmental Management Division, Terrestrial Standards and Studies Section. Report No. 84-4. 37 pp.

Lozano, F. C. and I. K. Morrison. 1982. Growth and nutrition of white pine and white spruce seedlings in solutions of various nickel and copper concentrations. J. Environ. Qual. 11. 437-441.

Malhotra, S. S. and R. A. Blauel. 1980. Diagnosis of air pollutant and natural stress symptoms on forest vegetation in western Canada. Environ. Canada, Can. For. Ser., Nor. For. Res. Ctre., Info. Rep. Nor-X-228. 84pp.

Malhotra, S. S. and A. A. Khan. 1981. Effects of SO_2 and heavy metals on Pinus banksiana. Mitteilungen der Forstlichen Bundesversuchsanstatt, Wien. 299-307.

Whitby, L. M. and T. C. Hutchinson. 1974. Heavy-metal pollution in the Sudbury mining and smelting region of Canada, II. Soil toxicity tests. Environ. Conservation. 1(3). 191-200.

Wotton, D. L. and G. D. Hogan. 1981. The effects of atmospheric emissions from the Thompson mining and smelting industry on forest vegetation and soils. Submission to the Clean Environment Commission, Prov. of Man. 112pp.

WETLAND STUDIES IN MANITOBA

G. F. Mills
Canada-Manitoba Soil Survey

ABSTRACT

The status and importance of wetlands in Manitoba and Canada is reviewed. The current system of wetland classification is summarized and maps showing wetland regions and distribution in Manitoba are introduced. The development of wetland inventories and the scope of special studies of wetland soils are described.

INTRODUCTION

Wetlands in Canada consist of bogs, fens, swamps, marshes and shallow open water areas such as the prairie potholes. The perspective regarding wetlands in Canada is changing. In the past wetlands have been commonly perceived as wastelands best converted to more productive uses (Lands Directorate, 1986). This viewpoint of wetlands is borne out by the millions of hectares which have been drained or filled for agriculture, highways, housing and industrial uses. However, treatment of wetlands has not been one of total and absolute exploitation. Private organizations such as Ducks Unlimited Canada, The Federation of Ontario Naturalists and the Manitoba Naturalists Society have been vocal in the past about the need to protect wetlands.

More recently both public and private awareness has increased of the importance of wetlands as wildlife habitat, moderators of watershed hydrology and recreational areas. National and local concerns are now raised about the extent and state of wetlands across the country; the degree of concern in any one area being related to the abundance and state of wetlands in that particular area. For example a study of wetland conversion and distribution in southern Ontario revealed that approximately 2.38 million ha of wetlands existed prior to settlement. By 1982, 0.93 million ha remained, a decline of 70 percent. Wetland loss has been most extensive in southwestern Ontario, where over 90 percent of the natural wetlands have been converted to other land uses, (Lynch-Stewart, 1983 and Lands Directorate, 1986).

Importance of Wetlands

In their natural state, wetlands provide hydrological, ecological and recreational functions. Wetlands are valuable habitat for a wide range of wildlife and unique and rare plant species. They also play a crucial role in the hydrology of watersheds by moderating flood peaks and storm runoff, modifying water quality and protecting shorelines against erosion. A wide range of educational and recreational opportunity are available in wetlands. Ecological reserves such as the Delta Marsh offer opportunities for demonstrating and observing ecological principles in a natural ecosystem.

In a managed state, wetlands may have direct economic benefit. Mineral wetlands such as marshes provide waterfowl habitat both as breeding areas and staging areas. Fur bearing habitat may be managed for trapping. Wild rice production may be viable on marshes in climatically suited areas. Marshes also may be used for ecological study

and research on the effects of management programs. Organic wetlands may provide forest production and wildlife habitat either in the natural state or when managed. Organic wetlands can be harvested for horticultural and other industrial uses. There is potential for fuel production and peatlands in climatically suited areas may be managed for cranberry and wild rice production in paddies and developed for agricultural production of crops, vegetables, tame and native hay and pasture.

The value of wetlands in both their natural and converted state has led to conflicts between wetland conservation and utilization. Resource-use conflicts arise through diversity of competing uses and resource values together with environmental implications of disrupting wetland functions.

What is a Wetland?

A wetland is defined as land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity which are adapted to a wet environment (National Wetlands Working Group, 1986). Wetlands include:

Organic Wetlands

- Peatlands which are characterized by more than 40 cm of peat accumulation on which Organic soils (excluding Folisols) develop.

Mineral Wetlands

- Mineral soil areas which are influenced by excess water but which for climatic, edaphic (factors related to soil), or biotic reasons, produce little or no peat. Gleysolic soils or peaty phases of Gleysolic soils are characteristic of these wetlands.
- Mineral soil areas of shallow open water which are generally less than 2 m deep. In certain of these wetlands vegetation is lacking and soils are poorly developed as a result of frequent and drastic fluctuations of surface water levels or of wave action, water flow, turbidity or a high concentration of salts or other toxic substances in the water or in the soil.
- Mineral soil areas which are modified by water-control structures (e.g. dams) or which are tilled and planted but which, if allowed to revert to their original state, become saturated for long periods and are then associated with wet soils (Gleysols) and hydrophytic vegetation.

WETLAND CLASSIFICATION

Development of a nationally applicable wetland classification system in Canada was first envisioned in 1973 with completion of an organic terrain classification system by the National Committee on Forest Lands. Subsequently a four-level hierarchical, ecologically based wetland classification system was proposed by Zoltai et. al. (1975). This system was refined for national usage by Tarnocai (1980). Various other workers refined regional classifications for Ontario (Jeglum et. al. 1974) and the Prairies (Millar, 1976). Other regional systems also exist for Quebec and for British Columbia.

The Canadian Wetland Classification System represents a synthesis of existing systems at the national level and was developed to its present form by the National Wetlands Working Group of the Canada Committee on Ecological Land Classification (NWWG, in press). The NWWG is comprised of many wetland scientists across Canada and promotes holistic, ecologically based management, use and conservation of Canadian wetlands. It acts through the informal support and contribution of federal, provincial,territorial and non-government agencies. This classification system continues to evolve as new research is undertaken and will be refined based on its field application.

The Canadian Wetland Classification System contains three hierarchical levels:

1) CLASS - recognizes overall genetic origin of wetland ecosystems. Five wetland classes are established.

2) FORM - differentiated based on surface morphology, surface pattern, water type and morphology of underlying soil. Seventy wetland forms are recognized.

3) TYPE - classified according to vegetation physiognomy.

KINDS OF WETLANDS

BOG WETLAND CLASS

A Bog is a peatland generally with the water table at or near the surface. The bog surface may be raised or level with the surrounding terrain, is virtually unaffected by nutrient-rich groundwaters and is thus generally acid and low in nutrients. The dominant materials are weakly to moderately decomposed Sphagnum and woody peat underlain at times by sedge peat. Soils are mainly Fibrisols, Mesisols and Organic Cryosols. Bogs may be treed or treeless and are usually covered with Sphagnum spp. and ericaceous shrubs. Eighteen bog wetland forms are recognized.

FEN WETLAND CLASS

A Fen is a peatland with the water table usually at or just above the surface. The waters are mainly nutrient-rich and minerotrophic from mineral soils. The dominant materials are moderately to well decomposed sedge and/or brown moss peat of variable thickness. The soils are mainly Mesisols, Humisols and Organic Cryosols. Vegetation consists predominantly of sedges, grasses, reeds and brown mosses with some shrubs and at times a sparse tree layer. Seventeen fen wetland forms are recognized.

MARSH WETLAND CLASS

A Marsh is a mineral wetland that is periodically inundated by standing or slowly moving water. Surface water levels fluctuate seasonally, with declining levels exposing drawdown zones of matted vegetation or mudflats. The waters are rich in nutrients varying from fresh to highly saline. The substratum usually consists of mineral material although occasionally it consists of well decomposed peat.

The soils are predominantly Gleysols with some Humisols and Mesisols. Vegetation occurs in zonal or mosaic surface patterns of pools or channels interspersed with clumps of emergent sedges, grasses, rushes and reeds bordering grassy meadows and peripheral bands of shrubs or trees. Submerged and floating aquatics flourish in open water areas. Fifteen marsh wetland forms are recognized.

SWAMP WETLAND CLASS

A swamp is a mineral wetland or peatland with standing water or water gently flowing through pools or channels. The water table is usually at or near the surface. The waters are rich in nutrients due to pronounced internal water movement from the margin or other mineral sources. If peat is present, it is mainly well decomposed wood peat underlain at times by sedge peat. Associated soils are Mesisols, Humisols and Gleysols. Vegetation is characterized by a dense cover of deciduous or coniferous trees or shrubs, herbs and some mosses. Seven swamp wetland forms are recognized.

SHALLOW WATER WETLAND CLASS

Shallow water is characteristic of intermittently or permanently flooded or seasonally stable water regimes, featuring open expanses of standing or flowing water which are variously called ponds, pools, shallow lakes, oxbows, reaches, channels or inpoundments. Mid summer water depths of less than 2 m distinguish shallow water from deep water and from other wetlands by summer open water zones occupying 75% or more of the wetland surface area. Living vegetation if present is confined to submerged and floating aquatic plant forms. Thirteen shallow water wetland forms are recognized.

WETLAND REGIONS AND DISTRIBUTION

The inventory and research activity that contributed to the development of a wetland classification for Canada also enabled the compilation of maps and related statistics showing wetland regions and distribution (National Wetlands Working Group, 1986). Regional differences in the development of wetlands are readily apparent in Canada. Some of these differences relate to the distribution or abundance of wetlands. The Manitoba portion of the map showing Wetland Distribution in Canada indicates those areas of the province characterized by high proportions of wetlands (Figure 1). Manitoba, because of its regional physiographic setting as a drainage catchment from some 1.06 million km^2 throughout western Canada (Figure 2) and because of its local physiography with extensive low lying poorly drained plains, has the highest wetland density per unit area in Canada (22.4 million ha or 41 percent of total area, Table 1). As indicated in Table 1 (Lands Directorate, 1986) and Figure 3 (Keating, M., 1987) Manitoba's wetland area is third largest in Canada next to Ontario and the Northwest Territories.

Although the distribution of different kinds of wetlands in Canada is often influenced by physiography, the development of trends and the establishment of specific kinds of wetlands can be attributed to climatic factors. Wetlands are dynamic ecosystems where an interaction of the biotic and abiotic environment produces specific physical and biological conditions.

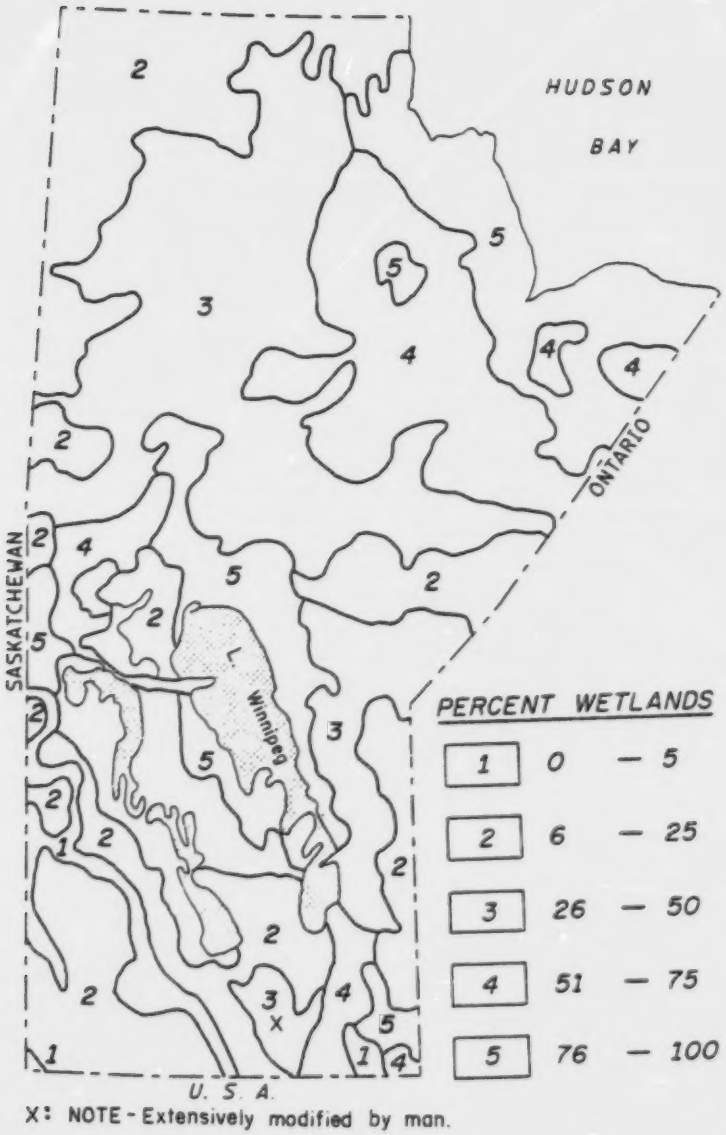

Figure 1. Wetland Distribution in Manitoba

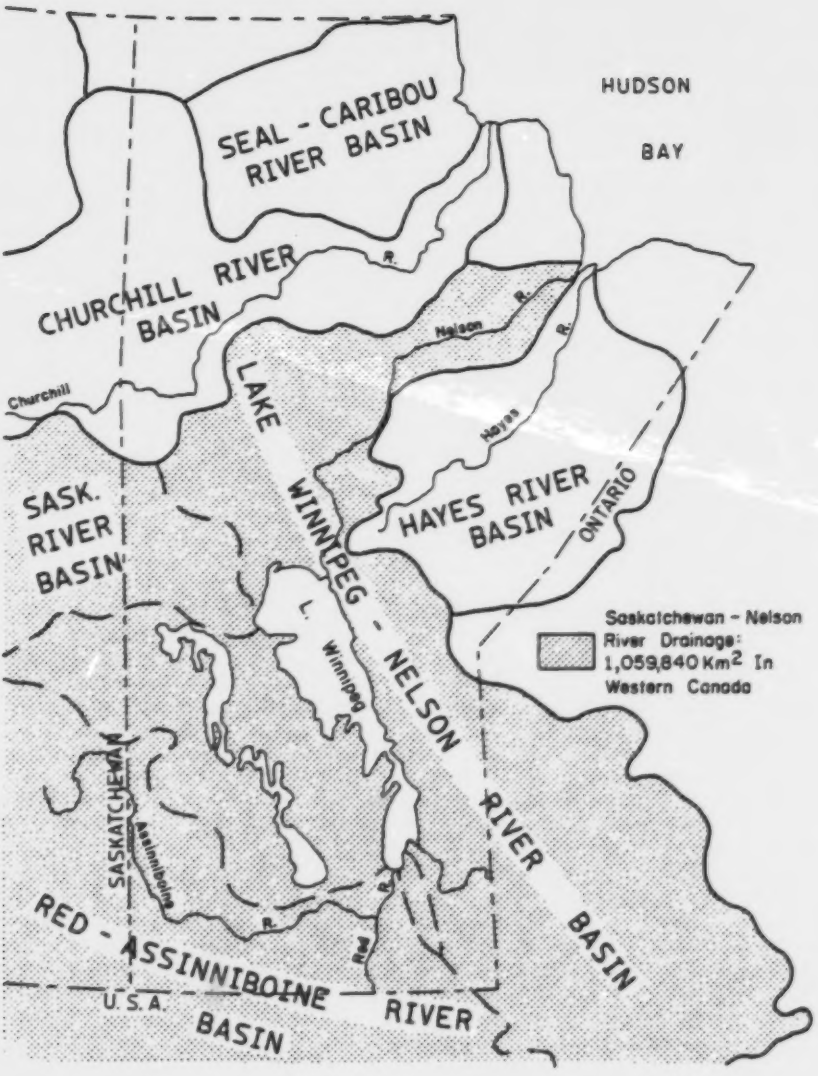

Figure 2. Drainage Basins of Manitoba Rivers

TABLE 1
Distribution of Wetlands in Canada

Province/Territory	Total Area of Wetlands (000's of ha)	% of Total Area	% of Total Canadian Wetlands
British Columbia	3 120	3	2
Alberta	13 740	21	11
Saskatchewan	9 687	17	8
Manitoba	22 470	41	18
Ontario	29 241	33	23
Quebec	12 151	9	10
New Brunswick	544	8	<1
Nova Scotia	177	3	<1
Prince Edward Island	4	<1	<1
Newfoundland-Labrador	6 792	18	5
Yukon	1 510	3	1
Northwest Territories	27 794	9	22
CANADA	127 230	14	100

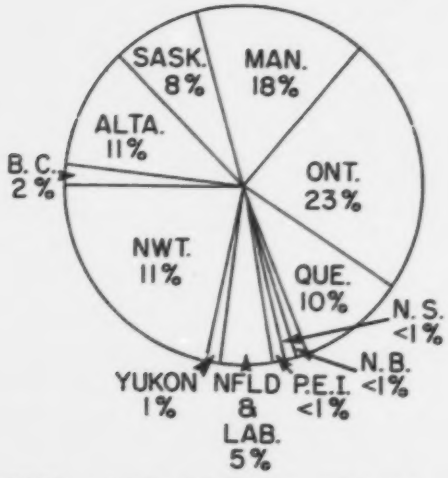

Figure 3. Canada's Wetlands - Distribution by Province and Territory

Factors such as water quality and quantity, peat formation, vegetation and organisms are continually interacting and reacting to changes brought about by other factors. The dynamic nature of wetlands results from these interactions taking place through time under climatic conditions that may change. Thus different wetlands develop under different conditions.

Climatic influence on wetland dynamics causes broad geographic regions to have characteristic wetlands. The Manitoba portion of the Wetland Regions of Canada map indicates a regionalization in wetland development which generally follows a north-south temperature gradient and an east-west precipitation gradient (Figure 4). Wetland regions are areas within which similar and characteristic wetlands develop on locations that have a similar topography, hydrology and nutrient regime. Subdivisions of wetland regions are based on the distribution of these wetlands, the relative abundance of the various kinds of wetlands (bogs, fens, swamps, marshes and shallow water) or developmental trends somewhat divergent to those in the rest of the region.

CHARACTERIZATION OF WETLAND SOILS

Soil characterization of the wetland environment provided by early soil surveys was relatively straightforward. In the 1940's soil association mapping delineated significant areas of wetland soils as poorly drained associates identified by on-site symbols for meadow, marsh and intermittent water bodies. Morphological characteristics of the associated wetland soil types were described in the report (Ellis, J. H. and W.H. Shafer, 1943).

Soil association maps published in the 1950's also indicated the location of wetland soils by on-site symbols for meadow-marsh and peaty meadow. In addition, on-site spruce swamp symbols indicated treed wetlands and organic soils were mapped as undifferentiated peat ie. organic soils of varying depth and type (Ehrlich et. al. 1956). Other soil surveys published in the 1950's had sufficient ground control to differentiate organic soil areas into Half Bog and Bog recognizing peat deposits of 12 to 30 inches thickness and deposits in excess of 30 inches respectively (Ehrlich et. al. 1958).

With the advent of soil series based mapping in the 1960's, individual soil series were established to recognize the soil conditions formerly described as poorly drained associates and shown on soil maps by on-site symbols. In addition, more complete description of the variability in organic terrain was provided. Three broadly defined organic soil complexes of shallow and deep peat were established: shallow peat (SP1, SP2 and SP3) and deep peat (DP1, DP2 and DP3) soil complexes recognized distinct combinations of ecological conditions in peat lands (Smith, R.E. and W.A. Ehrlich, 1964).

Organic soil mapping was further refined by using soil series and complexes of series to better describe the nature and depth of the different kinds of peat materials and the properties of the underlying mineral soil (Mills, G.F. and R.E. Smith 1971). This technique of describing organic terrain has continued to the present time with additional information related to organic landforms being incorporated into the description (Tarnocai, 1970) (Mills et. al. 1977).

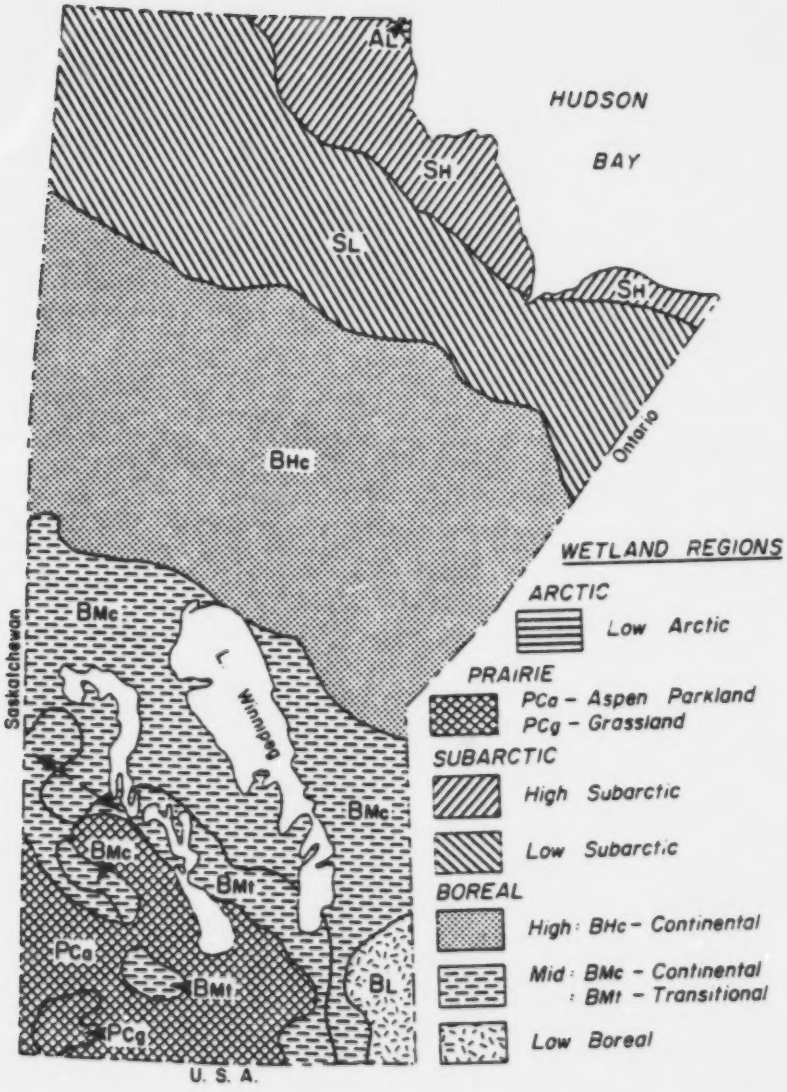

Figure 4. Wetland Regions in Manitoba

SPECIAL STUDIES OF WETLAND SOILS

Many studies of the wetland environment concentrate on specific components of wetlands. Vegetation, habitat and water management studies are funded through various Ducks Unlimited Canada Projects. Engineering studies key on topographic survey and surface drainage requirements to enhance agricultural land use. The study of wetland processes and dynamics are part of research programs in Departments of Botany and Natural Resource Management Institutes.

The inventory of wetland soils has evolved over the years to recognize wetland complexities and ecological relationships. A corresponding trend is evident in the supporting research to characterize wetland soils, processes, dynamics and ecology. In the past, special studies of wetland soils have often been in support of ongoing soil survey activities. Soil studies in the Pasquia area were initiated in 1946 and culminated in publication of a soil report and map in 1960 (Ehrlich et. al. 1960). This soil survey and accompanying salinity study ascertained the agricultural potential of this extensive area of marsh within the Saskatchewan Delta. A more recent soil survey of the Pasquia Lake bed in Polder III at The Pas evaluated the agricultural potential of the soils following drainage improvement. A special study of soil salinity in this wetland helped to assess both current, and potential salinity following reclamation (Mills et. al. 1984).

One of the first studies relating soils to groundwater characteristics took place in the Whitewater Lake basin of southwestern Manitoba. This research indicated that soil morphology and properties such as salt and carbonates are related to local and regional groundwater flow pattern and position in the landscape (Eilers, 1973). The effect of areas of groundwater discharge and recharge on soil properties and distribution was documented.

Some practical implications of established soil-groundwater relations associated with a slough were examined in a till plain near Hamiota in western Manitoba (Mills, J.G. and M.A. Zwarich, 1986). Knowledge of the groundwater flow system aids in determining the feasibility of slough drainage as well as the consequences of the drainage. Knowledge of soil properties and their distribution enables extrapolation of particular hydrologic condition to other areas where the groundwater characteristics are not known.

The influence of soil drainage regime on the chemistry and morphology of imperfectly drained sandy Black Chernozemic and associated Gleysolic soils has been studied in the Lower Assiniboine Delta in Manitoba (Michalyna, W. and R.H. Rust, 1984). A similar study on imperfectly drained clayey Black Chernozemic and associated Gleysolic soils was completed in the Red River Plain (Michalyna, W. and R.H. Rust, 1984). Such studies provide the data base necessary to support any proposed revisions to the Canadian System of Soil Classification.

A special soil and agronomic study was initiated in 1981 to assess the effects of drainage on groundwater levels and crop yields in wet sands and to develop recommendations on methods and feasibility of drainage (Regitnig P.J. et. al. 1983). The agronomic plots were located on a drainage and toposequence of soils from the Almasippi association.

Each soil type in the toposequence was characterized and a monitoring program put in place to measure crop yield, water table levels, soil temperatures and soil moisture. Two depths of controlled subsurface tile drainage were installed. The effect of the tiles on groundwater levels in the depressions (wetland soils) as well as on adjacent mid and upper slope position soils was determined. Information from the soil component of this study indicated the degree to which overdrainage could occur on these soils. Optimum water table control should be maintained at about 75 cm in the depressions or control structures would be required on outlets to prevent overdrainage in associated better drained portion of the landscape.

In recent years, interest has increased in the agricultural use of peatlands. Water table control in these organic soils is the main requirement for their agricultural use. However several other ongoing management concerns remain after reclamation and development. The best method of clearing, optimum levels of drainage, appropriate tillage practices, macro and micronutrient requirements for crops grown on peat and crop variety testing are all important research topics. Soil fertility research to date suggests that major plant nutrients are required to be in balance for optimum yield of crops grown on organic soils and micronutrients such as copper, manganese and boron are likely to be deficient and a limitation to plant growth (Sterkeman and Toews, 1984). The study of crop response to nitrogen and rates and methods of application of micronutrients is continuing in the Department of Soil Science at the University of Manitoba.

The temporal aspects of soil water regime are difficult to assess without benefit of sequential observations over time. Water table observations have been monitored on selected soil types as part of the resurvey program for some 25 years. More recent monitoring projects utilize a multi-discipline approach particularly well suited to wetland studies. A typical veneer bog wetland in the Thompson area has been characterized and monitored for both areal and temporal variation in thermal and hydrologic properties since 1981. A second objective of this study was to evaluate the descriptive and classification criteria for veneer bog wetlands (Mills et. al. 1987).

SUMMARY

Wetland studies in Manitoba include basic inventories of soil, vegetation and habitat as well as research into wetland processes and ecologic relations. Research studies often support inventory activities and as well are designed to quantify and define processes and relationships in the wetland ecosystem.

There is still only limited information about the status, ecological functioning and value (hydrologic, economic etc.) of Canadian wetlands. While gaps in the knowledge about wetlands remain, development plans and conservation measures must proceed without benefit from ongoing research activities. Recent progress in classifying and developing inventories of wetlands provides a framework to guide future work and a basis for extrapolation of existing research findings. Experience indicates that whether the concern is environmental, conservation, management or productivity, study of the soil component and research on soil-environment interaction is just as necessary in wetlands as it is in better drained landscapes.

REFERENCES

Ehrlich W.A., L.E. Pratt and E.A. Poyser, 1956. Reconnaissance Soil Survey of Rossburn and Virden Map Sheet Areas. Soils Report No. 6. Manitoba Soil Survey, Manitoba Dept. of Agriculture.

Ehrlich, W.A., L.E. Pratt, E.A. Poyser and F.P. LeClaire, 1958. Reconnaissance Soil Survey of West-Lake Map Sheet Area. Soils Report No. 8. Manitoba Soil Survey, Manitoba Dept. of Agriculture.

Ehrlich, W.A., L.E. Pratt, F.P. LeClaire and J.P. Barr, 1960. Detailed Soil Survey of Pasquia Map Area in Northern Manitoba. Soils Report No. 11. Manitoba Soil Survey, Manitoba Dept. of Agriculture.

Smith, R.E. and W.A. Ehrlich, 1964. Soil Survey of the South-Eastern Map Sheet Area. Soil Report No. 14. Manitoba Soil Survey, Manitoba Dept. of Agriculture.

Eilers R.G., 1973. Relations Between Hydrogeology and Soil Characteristics near Deloraine, Manitoba. Unpublished M.Sc. Thesis, University of Manitoba.

Ellis, J.H. and W.H. Shafer, 1943. Reconnaissance Soil Survey of South-Central Manitoba. Soils Report No. 4. Manitoba Soil Survey, Manitoba Dept. of Agriculture.

Jeglum, J.K., A.N. Boissonneau and V.F. Haavisto, 1974. Toward a Wetland Classification for Ontario. Canadian Forestry Service, Environment Canada. Information Report O-X-215. Sault Ste. Marie, Ontario.

Keating, M., 1987. Our Vanishing Wetlands. In Canadian Geographic Aug/Sept. 1987. pp. 42-51.

Lands Directorate, 1986. Wetlands in Canada: A Valuable Resource. Fact Sheet 86-4, Lands Directorate, Environment Canada, Ottawa, Ont.

Lynch-Stewart, Pauline, 1983. Landuse Change on Wetlands in Southern Canada: Review and Bibliography. Canada Land Use Monitoring Program. Working Paper No. 26. Lands Directorate, Environment Canada.

Michalyna, W and Rust R.H. 1984. Influence of Drainage Regime on the Chemistry and Morphology of Some Manitoba Soils: Sandy Chernozemic and Gleysolic Soils of the Lower Assiniboine Delta. Can. J. Soil Sci. 64: 587-604.

Michalyna, W. and Rust R.H. 1984. Influence of Drainage Regime on the Chemistry and Morphology of Some Manitoba Soils: Clayey Chernozemic and Gleysolic Soils of the Red River Plain. Can. J. Soil Sci. 64:605-620.

Millar, J.B., 1976. Wetland Classification in western Canada: a guide to marshes and shallow open water wetlands in the grasslands and parklands of the prairie provinces. Canadian Wildlife Service, Environment Canada. Report Series No. 37. Ottawa, Ontario. 38 p.

Mills, G.F. and R.E. Smith, 1971. Soils of the Grahamdale Area. Soils Report No. 16. Manitoba Soil Survey, Manitoba Dept. of Agriculture.

Mills G.F., L.A. Hopkins and R.E. Smith, 1977. Organic Soils of the Roseau River Watershed in Manitoba. Inventory and Assessment for Agriculture. Monograph No. 17. Manitoba Soil Survey, Canada Department of Agriculture.

Mills G.F., R.G. Eilers and N. Lindberg, 1984. Soil and Salinity Conditions in the Pasquia Lake Area of Polder III, Pasquia Land Settlement Project. Soils Report No. R28. Canada-Manitoba Soil Survey, Manitoba Dept. of Agriculture.

Mills G.F., H. Veldhuis, and Eilers, R.G., 1987. Thermal and Moisture Regime Characteristics of a Veneer Bog in North Central Manitoba In Proceeding of Wetlands' 87, Canadian Wetland Ecology and Conservation Symposium. August, 1987, Edmonton, Alberta.

Mills J.G. and Zwarich, M.A. 1986. Transient Groundwater Flow Surrounding a Recharge Slough in a Till Plain. Can. J. Soil Sci. 66:12-134.

National Wetlands Working Group. 1986. Canada's Wetlands. a) Canada-Wetland Regions; b) Canada-Distribution of Wetlands. Map Folio. Energy, Mines and Resources and Environment Canada, Ottawa, Ontario

NWWG, in press. The Canadian Wetland Classification System, National Wetlands Working Group. To be published in the Ecological Land Classification Series. Inland Waters/Lands Directorate, Environment Canada.

Regitnig, P.J., Racz G.J., Eilers R.G., and Hardman S.L., 1983. Project 408: Almasippi Wet Sands Management. Canada/Manitoba Subsidiary Agreement on Value-Added Crops Production, Agronomic Component Report submitted to Water Control Works Section, Water Resources Branch, Manitoba Dept. of Natural Resources.

Sterkeman, B. and Toews, E., 1984. Management Guidelines for Organic Soils. Proceedings of the 27th Annual Manitoba Society of Soil Science Meeting, University of Manitoba. pp.127-136.

Tarnocai, C. 1970. Classification of Peat Landforms in Manitoba. Canada Department of Agriculture, Research Station, Pedology Unit, Winnipeg, Manitoba.

Tarnocai, C. 1980. Canadian Wetland Registry. In Proceedings, Workshop on Canadian Wetlands. C.D.A. Rubec and F.C. Pollett, editors; Lands Directorate, Environment Canada, Ecological Land Classification Series No. 12.

Zoltai, S.C., F.C. Pollett, J.K. Jeglum and G.D. Adams. 1975. Developing a Wetland Classification for Canada. In Proceedings, 4th North American Forest Soils Conference. B. Bernier and C.H. Winget, editors. Laval University Press. Quebec, Quebec. pp. 497-511.

NEW DIRECTION FOR NATIONAL SOIL SURVEY IN CANADA

R.E. Smith
Canada-Manitoba Soil Survey

INTRODUCTION

As a public agency, the Soil Survey within Agriculture Canada must periodically examine its role and the way it follows its mandate. This not only ensures that we do not fall victim to inertia but also allows us to target those areas where our political masters and the public we serve have expressed a need for us to act. The work of the soil survey, or more properly the Inventory Section of the Land Resource Research Centre (LRRC) which coordinates the national soil survey program in Canada, has been changing recently and has been the subject of a number of reviews, the most significant of these being the Nielsen task force reviews of agricultural research and major surveys. While the fate of the Land Inventory Section's future is still not final, it is still an appropriate time to record the major parts of its program and the relative emphasis placed on each of those parts.

In 1986, each provincial unit across Canada forecast the type of work they anticipated doing, or were being asked to do by provincial advisory groups in the next 5 to 10 years. These forecasts were combined with revised Agriculture Canada priorities, colored by the Nielsen Task Force reviews, into a report by K.W. Valentine, the current head of the Inventory Section of LRRC and national coordinator of soil survey in Canada[1]. This report is now regarded as the definitive statement of our role as the Canada Soil Survey over the next 5 to 10 years. It is a current picture of its priorities and responsibilities for soil inventory work needed by Agriculture Canada and the Provinces. I must also emphasize at this point that it does not speak for any of the cooperating provincial units. But before getting to survey program specifics, a look at the role and organization of LRRC should be useful in providing some perspective or rationale for our work now and in the future.

THE ROLE AND ORGANIZATION OF LAND RESOURCE RESEARCH CENTRE

The role of the Land Resource Research Centre is to collect and research information on soil, climate and surface hydrology in Canada in order to assess and improve the potential of land for sustained agriculture and other land uses. More specifically, the role of the Land Inventory Section within the Centre is to provide reliable soil information, establish procedures for the computerized Canadian Soil Information System and to publish its findings in maps and reports.

To do this work, the Land Resource Research Centre (LRRC) has two principal sections, Inventory and Research, with Administration as a smaller third section (see Table 1). The rationale for this arrangement

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[1]Valentine, K.W. Oct. 15, 1987. Future Programs, Land Inventory Section, Land Resource Research Centre, Research Branch, Agriculture Canada. LRRC, Neatby Bldg., Ottawa, K1A 0C6.

is that both groups benefit. Inventory discovers, maps and assesses soil and land characteristics. Research takes these data, and with others from their own experiments, integrates them in studies on soil behavior, degradation, land evaluation and solute transfer. It follows that Inventory then allows the proper extrapolation of research results to land. Nonetheless, current senior branch management has expressed the viewpoint that surveys are a service rather than research and might be better located outside of the Research Branch.

Table 1. Organization of the Land Resource Research Centre 1987-88

	LRRC		
	Research Section	Administration Section	Inventory Section
PY's	81 (46)	15 (8)	91 (51)
Total Expenditures	3,853.4 (41)	892.8 (10)	4,646.7 (49)

ROLE AND ORGANIZATION OF THE RESEARCH SECTION, LRRC

The general organization and program structure of the Research Section of the Centre is based on a problem solving one rather than on a discipline or scientist driven one. Current programs and activities are being oriented to respond to soil and water conservation and the sustained optimum use of soil, water and climate resources (see Table 2). Additionally, more attention is being paid to the development of commodity oriented R & D programs, where solutions to unmarketable surpluses of many major crops and the potential to produce alternative crops must be examined. Production of alternative crops is a serious issue facing agriculture and policies and strategies will have to be developed to assist the adjustments that will be required. Many adjustments will involve significant change in land use. The core capability developed in LRRC to undertake such analyses and interpretations related to land use and evaluation will require strengthening. LRRC will continue to respond to these changing needs.

Table 2. Programs & Organization of Land Resource Research Centre

Research Section	Administration Section	Inventory Section
1. Land Use/Evaluation	1. Program Management	1. Inventory
2. Soil Management/ Conservation	2. Financial Management	2. Interpretation/ Land Evaluation
3. Water & Climate (Agrometerology)	3. Personnel Management	3. Procedures & Correlation
	4. Develop Operational Plans	4. Monitoring & Soil Quality
		5. Can. Soil Information System
		6. Cartography

NIELSEN COMMITTEE TASK FORCE REVIEW OF INVENTORY SECTION, LRRC

The direction for future work by federal soil survey has been strongly influenced by the Nielsen Committee Task Force review of agricultural research and federal major surveys. Some of their observations and suggestions include:

1. While the review of LRRC was fairly good, i.e., working well and meeting objectives, our unique federal-provincial-university cooperative work arrangements was praiseworthy and should be emulated by others; and while the committee recognized that the provinces would still like us to remain in inventory as in the past, changes to the program emphasizing application instead of just gathering data was recommended. That is, the committee questioned the balance in our program. They talked of contracting out surveys and the cartographic and information services to the private sector and to have us examine other options for soil survey. These investigations are still continuing.

2. The Inventory Section should concentrate more on work appropriate to a national organization keying on inventories appropriate to national requirement rather than provincial requirement; development of standards, procedures and quality control; development of land evaluation systems and national computerized soil information systems; monitoring soil quality changes. However, any program change must be made with the understanding and agreement of our provincial partners.

3. The Section should retain its close liaison with provincial governments and universities through formal institute agreements or informal working arrangements as in Manitoba. It should continue to emphasize work requested by provinces.

4. Regional Soil Survey units should remain largely autonomous to determine, in cooperation with the provinces, the details of our projects within the overall program. Our current working arrangement or rule of thumb is that regional soil survey units

shall retain control of 70% of their programs while Ottawa retaining the right to request up to 30% for national projects.

5. The Inventory Section should plan more contracting out and contracting in in its future programs, even though administrative and financial procedures for doing this may not be in place at present.

Table 3. Selected Surveys, Estimated Expenditures 1986 $ 000's (%)

		$	
Hydrographic Services		63,299	(8)
Forestry Statistics		2,392	(.3)
Geological Surveys		70,006	(9)
LRRC (Soil Survey)		7,650	(1)
Lands Directorate		5,457	(1)
CCRS		32,200	(4)
Stats Canada		206,996	(28)
Surveys and Mapping (NTS)		53,500	(7)
Total Federal Surveys Cost	approx.	750,000	
Total PY's	approx.	10,000	

Table 4. Estimated Expenditures on Soil Survey in a Selected Number of Countries, 1986*

Country	No. Surveyors	Agricultural Area in 10^6 ha	Percent Agric. Area Cultivated	Expenditures in millions Can. $
Canada	90	65.8	7.1	4.5
U.S.A.	1,350	134.0	14.6	97.5
U.K.	50	18.7	81.5	2.5
France	50	31.4	57.2	>2.5
Australia	20	21.9	2.8	>1.0
N.Z.	100	11.2	41.2	5.0

*LRRC Report to AC Nielson Implementation Committee

THE ROLE OF THE INVENTORY SECTION, LRRC

The Inventory Section's job is to provide reliable and up-to-date soil and land information that can be used for land use planning, protection and management now and in the future. It also establishes the procedures by which quality information is collected by its own scientists and by others. It also checks these procedures by correlation. It makes assessments of land quality appropriate to a number of different land uses from the information and develops the systems whereby such assessments are made. It undertakes, often with the Research Section the necessary applied research to do these jobs. It also cooperates with the Research Section on other research projects such as soil quality monitoring and land productivity evaluations. It maintains the necessary data management systems, such as the Canada Soil Information System (CanSIS) and the cartographic support services necessary to publish its information (see Table 5).

Table 5. Inventory Section Program Structure

1. National, Regional and Local Soil Mapping Projects

   - Fewer local projects will be started and more emphasis given to national projects such as the 1:1M scale maps and data base for the whole country.

2. Interpretations and Land Evaluations

   - Independent or cooperative projects to assess the potential of land mainly for agriculture and to develop systems for doing so.

3. Procedures and Correlation

   - Development of survey procedures and methods of quality control.

4. Monitoring and Soil Quality Change

   - Describing and measuring changes in soils that occur over time and relating those changes to concepts of quality.

5. Canadian Soil Information System (CanSIS)

   - Map and soil information is stored and analyzed in a computer using newly acquired ARC/INFO software; a Manitoba node is developing concurrently for local application.

6. Cartography and Computerized Map Information

   - Printed soil maps, visual display material will be produced.
   - Maps will be digitized for CanSIS and soil information will be computerized for national and regional application by Cartography.

ORGANIZATION OF THE INVENTORY SECTION, LRRC

To do the work as outlined, the Section is divided into four main units:

1. Regional Soil Survey Units

   There are LRRC survey units in each province and one in the Yukon Territory. In total there are fifty-eight soil scientists, technicians and clerks in the regions. They all work in close cooperation with provincial agencies and sometimes universities, often sharing resources.

2. Ottawa Correlation Unit

   There are three soil scientists (including K.W. Valentine, the section head) and two technicians in Ottawa working on projects of national scope and coordinating the development of soil survey procedures and correlation.

3. Canadian Information System (CanSIS)

   This group works on the computer support systems of CanSIS

and other projects for the LRRC. They are headed by one research scientist and a varying number of resource management technicians and computer scientists.

4. Soil Information and Cartographic Unit

This Ottawa based unit does all of the work to prepare soils maps, diagrams, etc. for all LRRC publications including maps and reports for cooperative surveys in the regions. They also digitize the soil maps for inclusion in CanSIS, prepare derived maps from original soil maps and will be responsible for storing and linking soil information to maps electronically (ARC/INFO-GIS). They also provide cartographic and visual display material for other groups in Agriculture Canada and other departments including Environment Canada. The unit has a total of thirty-one(31) people in drafting, computer, quality control and photo mechanical units.

PROGRAM ORGANIZATION AND STRUCTURE, INVENTORY SECTION, LRRC

All of the tasks of the Inventory Section fall into six major categories. Against each task is a percentage estimate to express in a very general way the proportion of resources (time and money) that should be allocated to them (Table 6). The estimates against the first four applies to the regional soil survey and Ottawa correlation units together. Each regional unit may not have exactly the same apportionment. The nature of the work under each of these categories is derived from provincial requests and Agriculture Canada's inventory needs over the next five to ten years. Current federal unit allocation of resources to each category of work in Manitoba indicates our need to make a significant adjustment of effort from the development of data bases under CanSIS to interpretations and land evaluation activities. We do not see any significant future shift away for inventory to other categories of work in Manitoba. Additionally, more effort is likely to occur in support of monitoring changes in soil quality over time. We see this latter activity as one where Soil Survey can play a significant role in Canada in the future.

Table 6. Projected Allocation of Resources (%) to Inventory Section Tasks

Categories of Work	Proportion of Resources: National Projection	Proportion of Resources: Current LRRC Manitoba
Work by Regional and Correlation Units		
1. Soil Inventory	30	36
2. Interpretations/Land Evaluations	30	10
3. Procedures and Correlation	30	20
4. Monitoring Soil Quality	10	4
Work by CanSIS Group		
5. Canadian Soil Information System	100	30
Work by Soil Information and Cartography		
6. Cartography and computerized map information	100	

MICRONUTRIENT INVESTIGATIONS ON ORGANIC SOILS 1985-87

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(A) COPPER:

Copper is an essential nutrient in crop production. It is required in relatively small amounts compared to major nutrients such as nitrogen and potassium. Therefore it is referred to as a micronutrient. Most mineral soils in Manitoba have levels of copper sufficient for crop production. However, in organic or peat soils copper deficiencies can be one of the major factors limiting crop production. In fact, the deficiencies at times can be extreme on these soils. Preliminary in field demonstrations in 1984 and 1985 showed that very large responses to copper fertilizer could be realized on deep organic soils in different regions of the province. A common observation in these demonstrations was yields in the nil range on the treatments that did not receive copper, whereas yields reached the 50-60 bushel per acre range on the copper treatments.

These preliminary observations lead to a series of more detailed investigations on deep organic soils in the Interlake and Eastern Regions. The investigations were set up with the following objectives in mind:

1. to compare different sources of copper fertilizer
2. to develop economic rates of application
3. to evaluate methods of application
4. to determine whether different times of application influence response.

Six investigations were initiated with barley in the Riverton, Stead and Whitemouth area during 1985-86-87. The barley variety in 1985 and 1986 was Argyle and Bedford in 1986. The observations are summarized as follows:

Response to Copper Fertilizer

Very large responses to copper fertilizer (table 1) were realized in three of the six investigations (see Riverton 1986, Whitemouth 1986 and Whitemouth 1987). On the three sites which

recorded responses the yields without copper fertilizer were very poor, (ranging from 2 to 19.3 bushels/acre). On these same three sites the average yield for all treatments that received copper fertilizer ranged from 28.0 to 51.1 bushels/acre. In one case the yields increased from 2.2 without copper to 82.5 bushels per acre by applying copper and the fungicide Tilt (Whitemouth 1987). The maximum response to copper at the other two responsive sites were: 2.0 to 48.4 bushels per acre at Whitemouth 1986 and 19.3 to 65.7 bushels per acre at Riverton 1986.

In this series of investigations crop response to copper fertilizer did not appear to be related to the amount of copper in the soil. The copper levels at all six sites were above the guideline used to flag possible deficiency problems on mineral soils (table 1). (On mineral soils deficiency problems may occur when copper levels in the soil are below 0.2 ppm). No response to fertilizer was observed on the Stead 1985 site which recorded the lowest soil copper level. However, on the site with the highest soil copper level (Whitemouth 1987) recorded an excellent response to additional copper fertilizer.

Sources of Copper Fertilizer

Three sources of copper fertilizer were compared; copper sulphate, EDTA chelate 7.5% copper and sequestered 5% copper. The products vary considerably in ease of application, costs and residual effect. Copper sulphate is a solid product (either granular of fine), can be difficult to apply, is very corrosive to fertilizer equipment and requires a substantial investment in the year of application. This form of copper may have a residual carry-over for a period of five to eight years. The EDTA chelate 7.5% copper and the sequestered 5% copper are liquid products and are relatively easy to apply (herbicide sprayers can be used). They require considerably less investment in the year of application than copper sulphate but reportedly do not have a residual effect after the year of application. EDTA copper chelate is more costly than sequestered copper. It is also reportedly a more effective source of copper than the sequestered product.

The effect of the three products on barley yield are compared in table 2. Two treatments, the fine grade copper sulphate and the dissolved and sprayed copper sulphate, although very effective in crop

response are not very practical for farm application. Copper sulphate is difficult to dissolve and once dissolved is very corrosive on most farm sprayer equipment. The problem with the fine grade copper sulphate is that most spin-type of fertilizer broadcast equipment is not able to apply it uniformly. Air-seeder type of fertilizer applicators should do a more uniform application of the fine grade copper sulphate; provided the product is not damp. If a spin-type of broadcast spreader is used, a granular form of copper sulphate can be applied more uniformly than the fine grade form. The fine grade can be less costly than the granular grade. Fertilizer equipment should be thoroughly washed after applying copper sulphate.

All three products, provided excellent responses to copper on the three responsive sites. The three products are compared in the following spring applied treatments; granular copper sulphate broadcast applied at 10 pounds copper, EDTA at 2 quarts and sequestered copper at 2 quarts per acre. The three site average yields for copper sulphate, EDTA and sequestered copper are as follows: 41.5, 57.2 and 50.3 bushels per acre respectively. At one site (Whitemouth 1987) applying copper sulphate in the previous fall produced significantly larger yields than a spring application. Economics, ease of application and residual effect should probably be the main factors in deciding which product to use.

Rates of Copper Fertilizer

When copper sulphate was the source of copper, the largest yields on 3 of 4 observations (table 2) were obtained with the 10 pound per acre copper treatment. The yields with lower rates of copper sulphate were usually considerably less. With EDTA copper chelate the average yields for the 2 and 1 quart rates were 57.2 and 51.1 bushels per acre respectively for the three sites. The added expense of the 2 quarts over the 1 quart/acre rate could not account for the extra 6.1 bushel per acre difference in yield.

Time of Copper Application

Yield comparisons for spring and fall application times are summarized in the Whitemouth 1987 investigation for granular grade copper sulphate and EDTA chelate, table 1. The fall application of

copper sulphate outyielded the spring application by a considerable 20.1 bushels per acre. However, with the two rates of EDTA, the spring applications outyielded the fall applications by 5 to 8 bushels per acre.

Methods of Copper Application

Three methods of applying copper sulphate were evaluated in 1986 at the Whitemouth and Riverton sites. The three methods included: (1) dissolving and spraying the copper sulphate on the soil surface followed by incorporation; (2) broadcast and incorporation of the granular product and (3) banding with the seed. Although dissolving and spraying produced the largest yields it is (as discussed before) not a practical farm method of application. Banding copper sulphate with the seed produced considerably less yield than the broadcast applications. The trials indicated that broadcast and incorporation is an effective and practical way of applying copper sulphate.

Foliar and preplant incorporation methods of application were evaluated for the EDTA chelate and the sequestered copper products. On two of the three sites the foliar application of EDTA was comparable to the preplant application but on the third site the yield was less than one-half. With the sequestered copper product the foliar applied yields were very much less than the yields on the preplant treatment.

SUMMARY

1. It is difficult to forecast a response to copper fertilizer by means of present day soil tests for copper on organic soils. The decision whether or not to fertilize with copper should be based on (a) recognizing deficiency symptoms in the field (b) tissue testing and (3) observed responses to application of copper to small areas of the field.

2. The three products; EDTA copper chelate, sequestered copper and granular copper sulphate are good sources of copper for cereal crops grown on deficient organic soils. When deciding which source to use consideration should be given to the economics, ease of application and the residual effect of these products.

3. For optimum results when using copper sulphate apply the equivalent of ten pounds of copper per acre as a broadcast treatment in the

fall. The copper sulphate should be incorporated prior to seeding. Do not band apply copper sulphate. Because copper sulphate reportedly provides a residual effect the cost of application should be considered over a 5 to 8 year period.

(4) EDTA copper chelate and sequestered copper fertilizers offer ease of application as compared to copper sulphate. The economics of product type and rate of application have to be considered. Results (table 2) show little yield difference between the 2 quart per acre sequestered and the 1 quart per acre EDTA preplant treatments. The two quart per acre EDTA treatment yielded only 6-7 bushels per acre more than the above two treatments. Spring applied EDTA will probably result in larger yields than fall applied.

(5) Foliar applications of EDTA chelate have merit as a salvage treatment. In cases where a deficiency is recognized very early in the growing season, a foliar application of 1 quart per acre EDTA may significantly increase the yield. Foliar applications may yield considerably less than the preplant treatments.

TABLE 1 BARLEY RESPONSE TO COPPER FERTILIZER

	Stead 1985	Riverton 1985	Riverton 1986	Whitemouth 1986	Whitemouth 1987	Riverton 1987
Without Copper Fertilizer	53.1	31.2	19.3	2.0	2.2	45.4
With Copper Fertilizer						
(a) average of all copper treatments	49.8	38.2	51.1*	28.0*	49.3*	42.5
(b) maximum observed yield			65.7	48.4	82.5	
Copper Levels in the Soil**	0.6 ppm	1.0 ppm	0.7 ppm	2.7 ppm	0.8 ppm	0.8 ppm

* Statistically significant response to copper fertilizer.

** According to mineral soil guidelines copper levels greater than 0.2 ppm in the soil are considered adequate for cereal crop production.

TABLE 2-COPPER FERTILIZER INVESTIGATIONS ON ORGANIC SOILS - SUMMARY OF OBSERVATIONS ON SITES WITH A SIGNIFICANT RESPONSE

PRODUCT	METHOD OF APPLICATION		RATE (per acre)	BARLEY YIELD (bushels per acre) WHITEMOUTH/86	RIVERTON/86	WHITEMOUTH/87	3 SITE AVERAGE
No Copper Applied				2.0	19.3	2.2	7.9
Copper Sulphate	Dissolve, Spray & Incorporate		10 lb Cu	48.4	65.7	46.9	53.7
Granular Grade Copper Sulphate	Broadcast & Incorporate	- spring	10 lb Cu	30.7	56.3	37.4	41.5
		- fall	10 lb Cu	-	-	57.5	
		- spring	5 lb Cu	11.4	57.4	-	
		- fall	5 lb Cu	-	-	22.7	
		- fall	2 lb Cu	-	-	8.5	
	Band with Seed		5 lb Cu	11.2	32.5	-	
			2 lb Cu	3.7	39.5	-	
Fine Grade Copper Sulphate	Broadcast & Incorporate	-spring	10 lb Cu	-	-	58.9	
EDTA Chelate 7.5% Copper	Spray & Incorporate	- spring	2 qts	47.2	61.9	62.4	57.2
		- fall	2 qts	-	-	57.2	
		- spring	1 qt	46.6	53.4	53.4	51.1
		- fall	1 qt	-	-	45.3	
	Foliar		1 qt	53.1	25.8	50.8	43.2
Sequestered 5% Copper	Spray & Incorporate	- spring	2 qts	52.4	40.8	57.8	50.3
	Foliar		1 qt	38.4	14.6	-	
Granular Grade Copper Sulphate plus Tilt	Dissolve, Spray & Incorporate		10 lb Cu/acre plus 2 applications of Tilt at 0.2 qts/acre/application			82.5	

(B) MANGANESE:

Manganese like copper is an essential micronutrient in crop production. Soil conditions which may lead to manganese deficiencies in crops are a shallow peat topsoil layer (usually less than 14 inches in depth) over a high line mineral subsoil. These soil conditions are found in several areas of the province. Manganese deficiencies have been observed on barley crops in the southern part of Interlake in the Oak Hammock marsh area. Deficiencies have also been observed on barley grown on the shallow peat soils found in the swales of the ridge and swale landscape of the Interlake and Winnipegosis areas. The occurence of low temperatures and dry soils early in the season may also enhance the deficiency. During the growing season under favorable conditions, the crops may outgrow the deficiency symptoms. By then however, damage resulting in yield loss may have occurred.

Response to Manganese Fertilizer

Three field trials were conducted on soils with a shallow layer of peat topsoil in the Oak Hammock area during 1985 to 1987. A response to manganese fertilizer was recorded in only one (1985) of the three years even though the trials were located in close proximity of one another in the same field. The manganese levels of the three trial sites were above the level considered deficient on mineral soils. Some observations from the 1985 trial on which response to manganese was recorded were (table 4):

1. A yield response to manganese fertilizer was reported on all treatments receiving a manganese fertilizer.
2. Slight yield differences were observed between the various manganese treatments. However, these differences were not statistically significant. In other words for all general purposes the yields on the manganese treatments could be considered to be equal.
3. The most economic preemergent treatment was banding manganese sulphate with the seed to supply the equivalent of five pounds of manganese per acre with the seed. Increasing the rate had no further significant effect on the yield.

4. The two foliar treatments (dissolved manganese sulphate and sequestered manganese) were also effective in increasing the yield of barley. (The dissolving of manganese sulphate was difficult when preparing the solution for foliar application).

SUMMARY

It is difficult to predetermine whether or not a response to manganese fertilization will be attained on the high line soils with a shallow peat topsoil. A response to manganese was observed in only one out of three years in the same field. Producers concerned about a manganese problem may want to try the following:

- band apply manganese sulphate at the equivalent of 9-13 pounds manganese per acre with cereal crops

The author would like to acknowledge the contributions and assistance of the following individuals:

B. Sterckeman
E. Toews
J. Maltman
G. Huebner
R. Siemens
E. Senkow
K. Watson
S. Jersak
H. Johnson

TABLE 3 BARLEY RESPONSE TO MANGANESE FERTILIZER

(bu/acres)

	1985	1986	1987
Without manganese fertilizer	33.9	32.3	55.9
With manganese fertilizer (average of all manganese treatments)	45.2*	35.0	60.5
Manganese levels in the soil**	1.5 ppm	1.5 ppm	4.8 ppm

Location of trials: Oak Hammock

* Statistically significant response to manganese fertilizer.

** According to mineral soil guidelines manganese levels greater than 1 ppm in the soil are considered adequate for cereal crop production.

TABLE 4 1985 MANGANESE FERTILIZER INVESTIGATIONS ON ORGANIC SOILS

PRODUCT	METHOD OF APPLICATION	RATE (per acre)	YIELD (bu/acre)
No manganese applied			33.9
Manganese Sulphate	Broadcast and Incorporate	30 lbs Mn	44.2
	Band with Seed Broadcast and Incorporate	5 lbs Mn 10 lbs Mn	45.5
	Band with Seed	5 lbs Mn	45.2
	Band with Seed	8 lbs Mn	46.8
Micro-mate	Band with Seed	10 lbs Mn	48.2
Sequestered Manganese	Foliar	3 pints	43.6
Manganese Sulphate + Water + Agral-90 (surfactant)	Foliar	8 lbs Mn SO_4 20 gallons 1.6 pints	43.1

WATER-USE EFFICIENCY OF WINTER AND SPRING WHEAT

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Abstract

Main block treatments of conventionally tilled spring wheat, zero tilled spring wheat and zero tilled winter wheat were established on a Manitou clay loam in the 1984-85 and 1985-86 crop years. Subplot treatments consisting of rates of applied-N, as urea, were post-seeding surface broadcast. Grain yields of each wheat-tillage regime were significantly increased by the applied-N. Water-use efficiency (based on grain yield) of each wheat-tillage regime was also increased by applied-N. Yields and water-use efficiencies were not significantly different between wheat-tillage regimes, although trends were apparent.

Introduction

Zero tillage production of wheat is relatively new on the eastern prairies. Zero tillage can result in increased snow trap and thus increased spring soil moisture (Staple et al, 1960; Smika and Whitfield, 1966; Aase and Siddoway, 1980). Zero tillage can also result in decreased spring soil moisture evaporative loss (Brun, 1985). Therefore, zero tillage may influence the water available for crop use and the water-use efficiency.

de Jong and Rennie (1969) determined water-use efficiency (WUE) as shown in Eg. (1).

$$WUE = \frac{\text{Yield}}{\text{Consumptive water use}} \qquad \text{Eq. (1)}$$

where: Consumptive water use =
spring soil moisture content +
precipitation -
harvest soil moisture content.

Water-use efficiency is thus influenced by those factors which affect yield, consumptive water use (CWU) and spring soil moisture (SSM).

Winter wheat is also relatively new on the eastern prairies. The earlier development and/or a different yield response to applied N of winter wheat may result in a different WUE response to applied-N than that for spring wheat.

This study was established to determine and compare the WUE (based on grain yield) response to applied-N of zero tilled winter wheat (ZT WW), zero tilled spring wheat (ZT SW) and conventionally tilled spring wheat (CT SW). This study is part of a larger study at two sites for three years and is thus a preliminary report.

Methods and Materials

The experiment was conducted on a Manitou clay loam (Orthic Black Chernozem) near Kaleida, Manitoba, during the 1984-85 and 1985-86 crop

years. Non-replicated main blocks for ZT WW, ZT SW and CT SW were laid out on a field of barley stubble (approximately 20 cm high) in the late summer prior to each crop year. The ZT main blocks were harrowed to spread straw, and sprayed with 1.10 L ha^{-1} of 356 g L^{-1} glyphosate prior to seeding to kill existing weeds. The CT main block was cultivated and harrowed in the early fall, and tandem disced and harrowed in the spring.

Six replicates of randomized subplots (2 m x 10 m) were laid out in each main block. Winter wheat (c. Norstar) was sown on September 7 in 1984 and on September 10 in 1985. Spring wheat (c. Neepawa) was sown on May 7 in 1985 and on May 21 in 1986. Seeding rate was 110 kg ha^{-1} and the seed placement depth was approximately 3 cm. The drill used was a Versatile Noble Model 2200 hoe-press drill with 10 hoes 19.6 cm apart.

All subplots received 25 kg P ha^{-1}, as 11-51-0, with the seed. This also provided 12 kg applied-N ha^{-1}. Further N, as 46-0-0, was surface-applied after seeding to create subplot treatments of 12, 30, 60, 90, 120, 180, 240 and 300 kg applied-N ha^{-1} for ZT WW and ZT SW; and 12, 60, 180 and 300 kg applied-N ha^{-1} for CT SW. Soil K and SO_4-S levels were considered adequate (Table 1).

Soil moisture contents at time of spring wheat seeding and at harvest time of the respective wheats were determined gravimetrically on selected subplots to a 60 cm depth in 1985 and to a 120 cm depth in 1986. The selected subplots included the 12, 60, 90, 180 and 300 kg applied-N ha^{-1} treatments of the ZT wheats and all treatments of the CT SW, in three of the six replicates. Soil moisture was determined in 0-15, 15-30, 30-60, 60-90 and 90-120 cm increments.

Herbicides and fungicides were applied as required at recommended rates.

Statistical analysis was conducted under release 5.16 of SAS, on the University of Manitoba mainframe computer. The PROCEDURE REGRESSION was used to produce the regression line-of-best-fit (predicted line) and upper and lower 95% confidence bands. The confidence bands (of the mean treatment value) allowed comparison between rates of applied-N and between wheat-tillage regimes. The PROCEDURE GPLOT was used to graph the line-of-best-fit. Tables corresponding to each Figure show the values of the line-of-best-fit, the confidence bands and the average of the actual data.

Results and Discussion. 1984-85 Crop Year.

The 1984-85 plot site soil NO_3-N content for the 0-60 cm depth was 37.5 kg ha^{-1}, which is considered medium[1]; and, for the 0-120 cm depth was 69.5 kg ha^{-1} (Table 1).

Average SSM contents for ZT WW and ZT SW were similar and slightly greater than that for CT SW (Table 2). This difference was probably due to the standing stubble in the ZT main blocks trapping more snow, a portion of which increased the SSM content (Staple et al, 1960; Smika

[1] Manitoba Provincial Soil Testing Laboratory

and Whitfield, 1966; Aase and Siddoway, 1980) and/or, the standing stubble decreasing evaporative loss of SSM (Brun, 1985).

Precipitation was monitored on a daily basis at the plot site during the growing season. Precipitation from the Morden CDA weather station (approximately 26 kg ENE of the plot site) was used to compare the crop year with the long-term average, thereby characterizing the crop year precipitation. This comparison indicated that the 1984-85 non-growing season precipitation was similar to that of the long-term average. May precipitation was near normal also, however, the months of June and August were considerably wetter and July was considerably drier than the long-term average (Table 3).

Consumptive water use was not affected by the rate of applied-N. Equations for the CWU response to applied-N exhibited very low R-square values, thus the rate of applied-N did not affect CWU. Furthermore, CWU averaged for each wheat-tillage regime, indicated there was little difference between the wheat-tillage regimes (Table 2).

Grain yield of each wheat-tillage regime was significantly increased by the application of N, although the rate of applied-N responsible for maximum yield varied (Figure 1 and Table 4). Yield of CT SW increased with increased rates of applied-N up to 300 kg ha^{-1}, whereas yields of ZT SW and ZT WW increased with increased rates of applied-N up to 240 kg ha^{-1} and then slightly and not significantly decreased with 300 kg applied-N ha^{-1}.

At each rate of applied-N, the difference between wheat-tillage regimes with respect to grain yield was not significant, except at 240 kg applied-N ha^{-1} where ZT WW significantly outyielded ZT SW. However, trends are apparent. Generally, ZT SW outyielded CT SW. Also, at low rates of applied-N ZT SW outyielded ZT WW, whereas at medium and high rates of applied-N ZT WW outyielded ZT SW.

Water-use efficiency of each wheat-tillage regime was increased by the application of N, however, this increase was significant only for ZT WW and ZT SW (Figure 2 and Table 5). Furthermore, the rate of applied-N responsible for maximum WUE varied between wheat-tillage regimes. Water-use efficiency of CT SW and ZT WW increased with increased rates of applied-N up to 300 kg ha^{-1}, whereas that of ZT SW increased with increased rates of applied-N up to 180 kg ha^{-1} and then decreased, although not significantly with 300 kg applied-N ha^{-1}.

At each rate of applied-N, the difference between wheat-tillage regimes with respect to WUE was not significant. However, trends similar to those for grain yield are apparent. Water-use efficiency of ZT SW generally surpassed that of CT SW. Furthermore, at low rates of applied-N the WUE of ZT SW surpassed that of ZT WW, whereas at high rates of applied-N the WUE of ZT WW surpassed that of ZT SW.

1985-86 Crop Year

The 1985-86 plot site soil NO_3-N content for the 0-60 cm depth was 33.6 kg ha^{-1}, which is considered medium minus[1]; and, for the 0-120 cm depth was 47.4 kg ha^{-1} (Table 1).

[1]Manitoba Provincial Soil Testing Laboratory.

Average SSM content was similar for each wheat-tillage regime (Table 6), which differs from the first crop year data. Data from the Morden CDA weather station (Table 7) showed that for April 1986 precipitation was greater than twice the long-term average. Furthermore, 64 of the 67 mm of precipitation that fell at the plot site during May occurred in the first 11 days of the month. Therefore, the lack of difference in SSM content between zero and conventional tillage was likely due to the high precipitation during April and early May, i.e. prior to soil sampling and seeding. Holt et al. (1964) similarly reported that high precipitation in the spring decreased the yield advantage due to greater spring soil moisture.

The 1985-86 non-growing season precipitation was slightly greater than the long-term average. Precipitation received in May was approximately normal and in July was near normal, however, June was drier and August was very much drier than the long-term average.

As with the first crop year results, CWU was not affected by the rate of applied-N. Conversely, however, average CWU varied between wheat-tillage regimes (Table 6). The average CWU of the zero tilled wheats was similar but substantially less than that of CT SW. This difference between zero and conventional tillage was probably due to greater soil moisture evaporative loss from the conventional tillage. Brun (1985) has also reported a lower evaporative loss from stubble land than from bare soil.

Grain yield of each wheat-tillage regime was significantly increased by the application of N and maximum yield was reached at a rate of applied-N less than the maximum (Figure 3 and Table 8). Yield increased with increased rates of applied-N up to 240 kg ha^{-1} for ZT SW, and up to 180 kg ha^{-1} for CT SW and ZT WW. Yield of each wheat-tillage regime then decreased, although not significantly with further applications of applied-N.

At each rate of applied-N, the difference between wheat-tillage regimes with respect to grain yield was not significant. However, ZT WW slightly outyielded both zero and conventionally tilled spring wheat. Also, at low rates of applied-N CT SW slightly outyielded ZT SW, whereas at high rates of applied-N ZT SW outyielded CT SW.

Water-use efficiency of each wheat-tillage regime was increased by the application of N, however, this increase was significant only for ZT WW (Figure 4 and Table 9). Water-use efficiency of each wheat-tillage regime increased with increased rates of applied-N up to 180 kg ha^{-1} and then decreased, although not significantly, with 300 kg applied-N ha^{-1}.

Considering the similarity of the CWU and grain yield between ZT WW and ZT SW, differences between these wheat-tillage regimes with respect to WUE, would not be expected. However, because WUE was calculated from yield and soil moisture samples from selected plots in three replicates only, there was some variation from the expected based on six replicates. At each rate of applied-N, the difference between wheat-tillage regimes with respect to WUE was not significant, except at 300 kg applied-N ha^{-1} where ZT WW significantly surpassed CT SW. However, the WUE generally decreased in the order of ZT WW > ZT SW > CT SW.

Summary

Spring soil moisture content was similar for the zero tilled wheats and lesser for CT SW, in the first crop year; and, similar for each wheat-tillage regime, in the second crop year.

Consumptive water use was similar for each wheat-tillage regime in the first crop year; and, similar for the zero tilled wheats and greater for CT SW in the second crop year.

Grain yield of each wheat-tillage regime was significantly increased by the application of N in both crop years. The WUE of each wheat-tillage regime was also increased by the application of N in both crop years.

Grain yield and WUE of ZT SW generally surpassed those of CT SW, in the first crop year. At low rates of applied-N the grain yield and WUE of ZT SW surpassed those of ZT WW, whereas at high rates of applied-N the grain yield and WUE of ZT WW surpassed those of ZT SW.

Grain yields were similar for each wheat-tillage regime, however, WUE generally decreased in the order of ZT WW > ZT SW > CT SW, in the second crop year.

References

Aase, K. and Siddoway, F.H. 1980. Stubble height effects on seasonal microclimate, water balance and plant development of no till winter wheat. Agric. Meteor. 21:1-20.

Brun, L. 1985. Evaporation from bare and stubble-covered soil. Proc. 7th Ann. Mb.-N.D. Zero Tillage Workshop. pp. 52-54.

De Jong, E. and Rennie, D.A. 1969. Effect of soil profile type and fertilizer on moisture use by wheat grown on fallow or stubble land. Can. J. Soil Sci. 49:189-197.

Holt, R.F., Timmons, D.R., Voorhees, W.B. and Van Doren, C.A. 1964. Importance of stored soil moisture to the growth of corn in the dry to moist subhumid climatic zone. Agron. J. 56:82-85.

Smika, D.E. and Whitfield, C.J. 1966. Effect of standing wheat stubble on storage of winter precipitation. J. Soil Water Conserv. 21:138-141.

Staple, W.J., Lehane, J.J. and Wenhardt, A. 1960. Conservation of soil moisture from fall and winter precipitation. Can. J. Soil Sci. 40:80-88.

Table 1. Soil characteristics.

Characteristic (depth)	1984-85	1985-86
pH, water extract		
(0-15 cm)	7.2	5.9
Conductivity (dSm^{-1}), water extract		
(0-15 cm)	0.50	0.26
Organic matter (%)		
(0-15 cm)	5.5	5.3
NO_3-N ($kgha^{-1}$), $CuSO_4$ extractable		
(0-60 cm)	37.5	33.6
(0-120 cm)	69.5	47.4
P ($kgha^{-1}$), $NaHCO_3$ extractable		
(0-15 cm)	7.1	11.6
K ($kgha^{-1}$), NH_4OAc extractable		
(0-15 cm)	549	634
SO_4-S ($kgha^{-1}$), $CaCl_2$ extractable		
(0-60 cm)	416.9	14.6
(0-120 cm)	1429.2	29.3

Table 2. Spring soil moisture content (mm) and consumptive water use (mm) 1985.

Wheat-till regime	Spring soil moisture	Consumptive water use
Zero tilled winter wheat	232	344
Zero tilled spring wheat	229	350
Conventionally tilled spring wheat	215	353

Table 3. Monthly precipitation (mm) at the plot site and Morden CDA weather station in 1984-85, and long-term[1] average monthly precipitation (mm) at the Morden CDA weather station.

Location	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept. to Apr.	May to Aug.
							1984-85							
Plot site	-	-	-	-	-	-	-	-	51	125	22	141	-	339
Morden	32.4	117.6	22.6	23.8	9.0	17.3	13.4	14.6	60.8	115.8	40.6	194.4	250.7	411.6
							Long-term average							
Morden	51.9	31.5	25.6	22.3	23.5	19.1	28.3	41.4	66.3	75.8	73.2	71.1	243.6	286.4

[1] 1951-1980, inclusive.

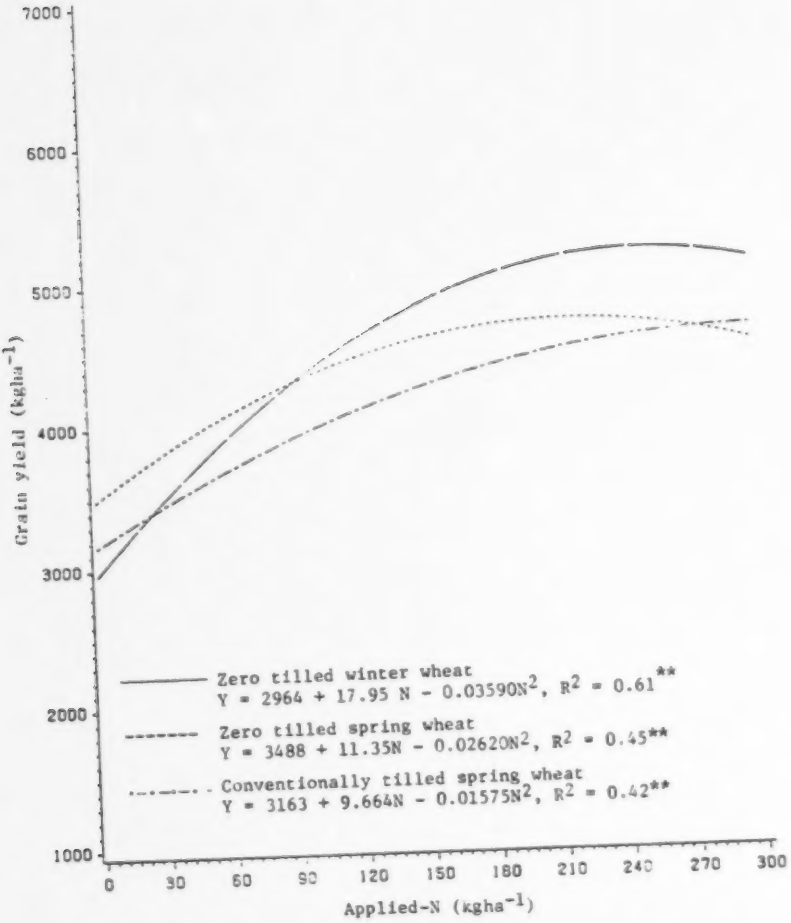

Figure 1. Grain yield as affected by rate of applied-N (1985)

Table 4. Averages and regression parameters for grain yield as affected by rate of applied-N (1985).

Applied-N (kgha-1)	Wheat-till regime (kgha-1)											
	Zero tilled winter wheat				Zero tilled spring wheat				Conventionally tilled spring wheat			
	Averages of actual data	Predicted line	Upper 95% C.L.[1] band	Lower 95% C.L. band	Averages of actual data	Predicted line	Upper 95% C.L. band	Lower 95% C.L. band	Averages of actual data	Predicted line	Upper 95% C.L. band	Lower 95% C.L. band
12	2969	3180	3539	2822	3498	3624	3880	3368	3012	3280	3801	2758
30	3461	3470	3750	3190	3791	3805	4005	3605	--	--	--	--
60	4205	3912	4129	3694	4216	4074	4230	3919	4134	3686	4063	3308
90	4321	4289	4521	4056	4494	4297	4463	4131	--	--	--	--
120	4761	4601	4868	4334	4292	4472	4663	4282	--	--	--	--
180	4648	5031	5320	4743	4759	4682	4888	4476	4137	4392	4920	3864
240	5260	5203	5476	4931	4495	4703	4897	4508	--	--	--	--
300	5179	5117	5566	4668	4646	4535	4855	4214	4719	4644	5226	4063

[1] confidence limit.

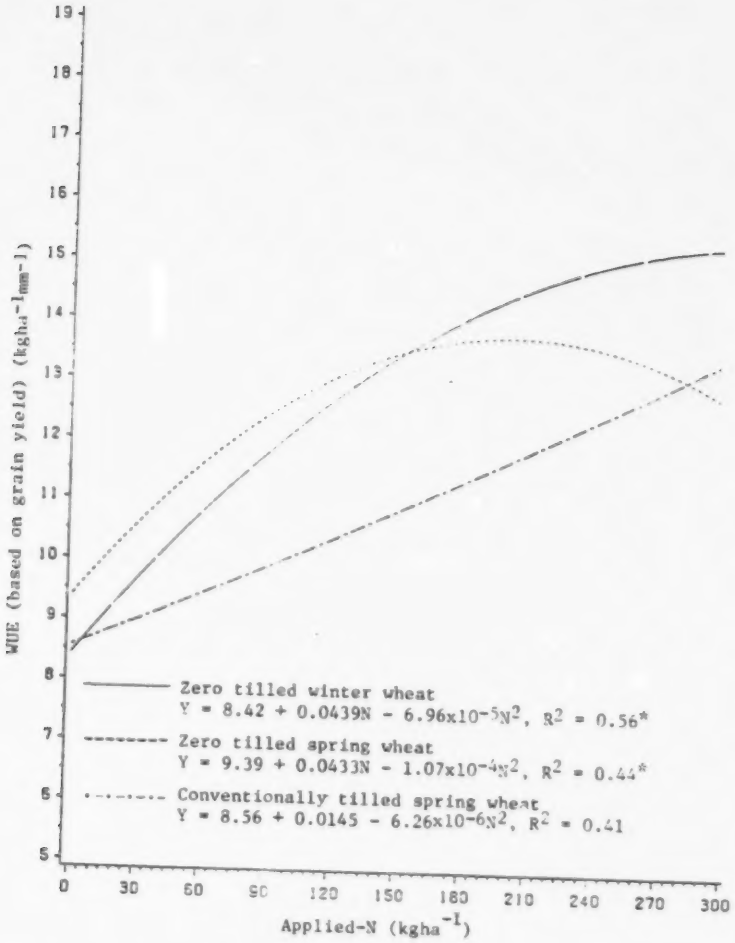

Figure 2. WUE (based on grain yield) as affected by rate of applied-N (1985)

Table 5. Averages and regression parameters for WUE (based on grain yield) as affected by rate of applied-N (1985).

Applied-N (kgha-1)	Wheat-till regime (kgha-1mm^{-1})											
	Zero tilled winter wheat				Zero tilled spring wheat				Conventionally tilled spring wheat			
	Averages of actual data	Predicted line	Upper 95% C.L.[1] band	Lower 95% C.L. band	Averages of actual data	Predicted line	Upper 95% C.L. band	Lower 95% C.L. band	Averages of actual data	Predicted line	Upper 95% C.L. band	Lower 95% C.L. band
12	7.88	8.95	11.60	6.30	10.03	9.91	11.69	8.12	7.42	8.73	11.66	5.80
60	13.56	10.80	12.49	9.12	11.25	11.60	12.70	10.50	11.65	9.44	11.57	7.32
90	11.74	11.81	13.62	10.00	12.65	12.42	13.62	11.22	--	--	--	--
180	13.08	14.07	16.37	11.77	13.74	13.72	15.29	12.15	10.10	11.36	14.33	8.39
300	15.63	15.34	18.24	12.43	12.74	12.76	14.75	10.76	13.82	13.45	16.72	10.19

[1] confidence limit.

Table 6. Spring soil moisture content (mm) and consumptive water use (mm) 1986.

Wheat-till regime	Spring soil moisture	Consumptive water use
Zero tilled winter wheat	522	346
Zero tilled spring wheat	517	345
Conventionally tilled spring wheat	535	397

Table 7. Monthly precipitation (mm) at the plot site and Morden CDA weather station in 1985-86, and long-term[1] average monthly precipitation (mm) at the Morden CDA weather station.

Location	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept. to Apr.	May to Aug.
							1985-86							
Plot site	--	--	--	--	--	--	--	--	67	59	68	23	--	217
Morden	23.4	39.2	54.4	10.2	16.2	11.0	11.4	96.6	77.0	34.8	99.2	19.6	262.4	230.06
							Long-term average							
Morden	51.9	31.5	25.6	22.3	23.5	19.1	28.3	41.4	66.3	75.8	73.2	71.1	243.6	286.4

[1] 1951-1980, inclusive.

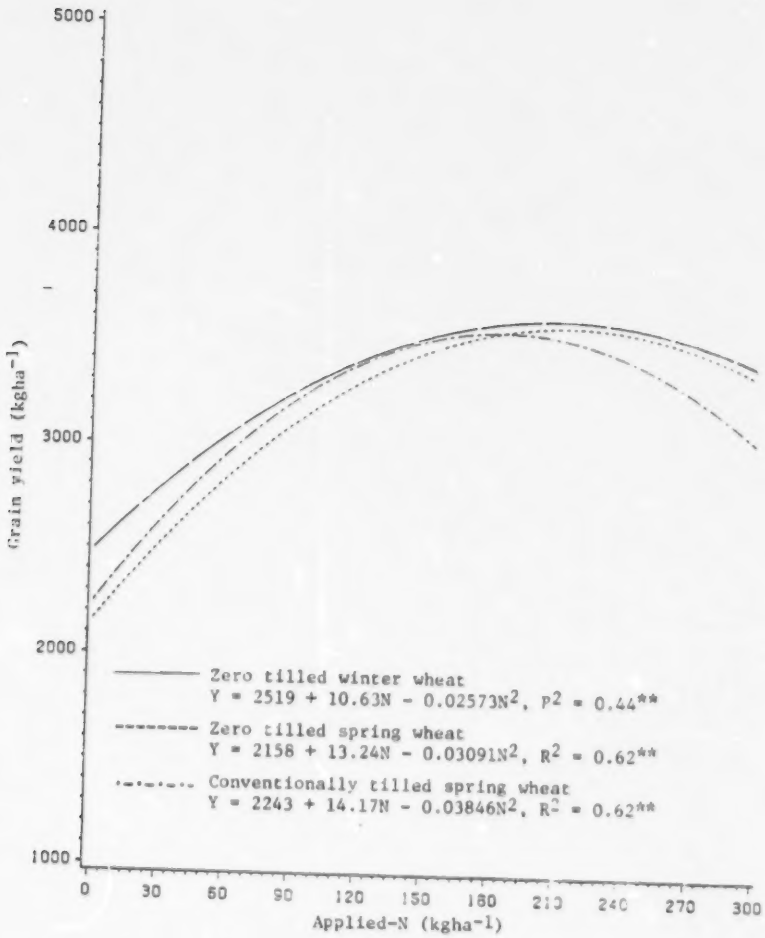

Figure 3. Grain yield as affected by rate of applied-N (1986).

Table 8. Averages and regression parameters for grain yield as affected by rate of applied-N (1986).

Applied-N (kgha-1)	Wheat-till regime (kgha-1)											
	Zero tilled winter wheat				Zero tilled spring wheat				Conventionally tilled spring wheat			
	Averages of actual data	Predicted line	Upper 95% C.L.[1] band	Lower 95% C.L. band	Averages of actual data	Predicted line	Upper 95% C.L. band	Lower 95% C.L. band	Averages of actual data	Predicted line	Upper 95% C.L. band	Lower 95% C.L. band
12	2407	2647	2880	2413	2096	2317	2528	2105	2279	2412	2664	2160
30	2995	2815	2998	2632	2524	2527	2692	2362	--	--	--	--
60	3159	3064	3207	2921	3093	2841	2970	2713	3177	2955	3137	2772
90	3316	3267	3419	3115	3246	3099	3236	2962	--	--	--	--
120	3477	3424	3598	3250	3292	3302	3459	3144	--	--	--	--
180	3518	3598	3785	3412	3454	3540	3710	3370	3421	3548	3803	3293
240	3445	3587	3764	3411	3312	3556	3717	3395	--	--	--	--
300	3494	3391	3682	3101	3514	3349	3614	3084	3070	3033	3315	2752

[1] confidence limit.

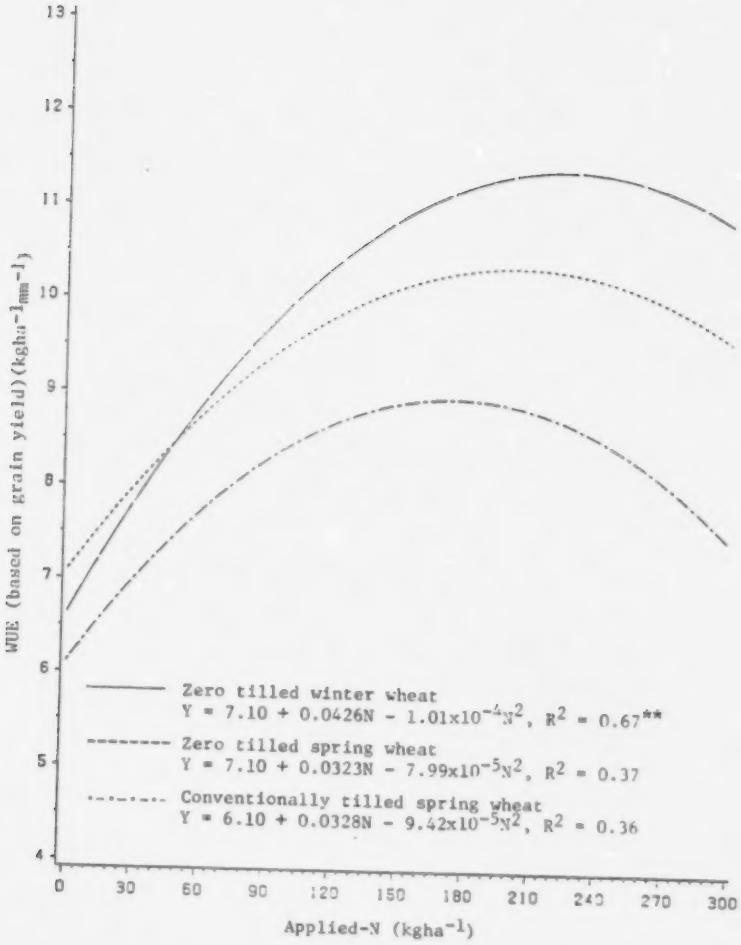

Figure 4. WUE (based on grain yield) as affected by rate of applied-N (1986).

Table 9. Averages and regression parameters for WUE (based on grain yield) as affected by rate of applied-N (1986).

Applied-N (kgha-1)	Wheat-till regime (kgha-1mm^{-1})											
	Zero tilled winter wheat				Zero tilled spring wheat				Conventionally tilled spring wheat			
	Averages of actual data	Predicted line	Upper 95% C.L.[1] band	Lower 95% C.L. band	Averages of actual data	Predicted line	Upper 95% C.L. band	Lower 95% C.L. band	Averages of actual data	Predicted line	Upper 95% C.L. band	Lower 95% C.L. band
12	7.29	7.61	8.86	6.35	7.32	7.48	9.02	5.94	6.27	6.50	8.06	4.94
60	9.92	9.28	10.08	8.49	8.21	8.75	9.70	7.80	8.11	7.73	8.86	6.60
90	10.27	10.11	10.96	9.25	10.59	9.36	10.39	8.32	--	--	--	--
180	11.11	11.48	12.57	10.39	9.63	10.33	11.68	8.97	8.74	8.95	10.53	7.37
300	10.88	10.77	12.15	9.40	9.76	9.60	11.33	7.88	7.52	7.46	9.20	5.72

[1] confidence limit.

MEASUREMENT OF WATER EROSION IN MANITOBA

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ABSTRACT

Soil erosion measurements under natural rainfall were made on selected soil types in Manitoba agricultural fields. The purpose of these measurements was to obtain a sufficient data base for evaluating the utility of the Universal Soil Loss Equation (USLE) under Manitoba agricultural conditions. The soil types used were a Gretna clay, a Leary sandy loam, a Ryerson loam and a Carroll clay loam. The measurements were made on different crop management treatments: summerfallow, corn, conventional tillage wheat, minimum tillage wheat, and alfalfa. Measurements of rainfall, soil loss, crop cover, and soil moisture were done throughout the growing seasons of 1986 and 1987. Physical properties of the different soil types were also measured. The data obtained was used in evaluating the soil erodibility and crop cover factor values, and comparing these to estimates made from the USLE. The results showed significant differences in soil loss for the different soil types and cropping management treatments.

INTRODUCTION

The problem of persistent soil erosion, especially by rainfall, has been recognized in many parts of the world as a serious threat to sustained agricultural production. The erosion process involves detachment and transportation of soil particles by excess rainwater, in the form of surface runoff, and deposition down-slope in the same field or watershed. The effects of erosion on long term productivity of the soil are related to reduction in waterholding capacity, mixing clayey subsoil into silty topsoil and a decrease in effective rooting depth to less than optimum requirements for plant growth. The other related effects are loss of organic matter, deterioration of soil structure, increased bulk density, tendency to crust formation, diminished workability, loss of plant nutrients, lower pH and resulting high lime requirement. These effects can be corrected through proper management but at a high cost.

The most common method of estimating rainfall erosion in many parts of the world is the Universal Soil Loss Equation (USLE). The equation is an erosion model that was developed in the United States.It is an attempt to obtain a basis for an effective soil conservation strategy by predicting the magnitude of soil erosion events under different crop management systems. The equation is therefore expected to be used as a soil conservation tool in specific agricultural resource planning and management activities for ensuring proper land management practices for reducing soil loss to tolerable levels. The equation, in its present form, is a combination of six factors that include the various factors that contribute to the erosion process.

The development of the USLE depended upon the analysis of 10,000 plot years of data from about 50 locations distributed in 24 states east of the Rockies. It is an empirically derived parametric model expressed as:

$$A = R \times K \times L \times S \times C \times P$$

where:

A = average annual soil loss (t/ha)
R = rainfall erosivity factor, which is the number of rainfall erosion index units in a particular storm or year. The index is a measure of the erosive force of a specific rainstorm.
K = soil erodibility factor, which is the erosion rate per unit of rainfall erosion index for a specific soil in cultivated continuous fallow on a 9% slope, 22.13 m long.
L = slope-length factor, which is the ratio of soil loss from a field slope length to that from a 22.13 m long slope on the same soil type and slope gradient.
S = slope-gradient factor, which is the ratio of soil loss from the existing slope gradient to that from a 9% slope. (Usually the factors L and S are combined into one term.)
C = crop cover and management factor, which is the ratio of soil loss from a field with specified cropping and management to that from the fallow condition on which the K factor was evaluated.
P = soil conservation support practice factor, which is the ratio of soil loss with contouring, strip cropping or terracing to that with straight row farming, up and down the slope.

There are a number of field conditions relating to soil type and crop management systems that limit the direct application of the USLE under Manitoba conditions. Compared to the soils for which the USLE was developed, the Prairie agronomic and climatic factors have contributed to higher organic matter. The soils were developed from parent materials with a different clay mineralogy and under a more humid cooler climate. Also, many of the crops grown on the Prairies are different from those grown in the United States to the south. These differences cast doubt on the reliability of estimates of K and C by existing methods.

The K values derived from the Wischmeier et al. (1971) nomograph may not be applicable to Canadian Prairie conditions, since the highest organic matter content considered in the nomograph was 4.0%. Most Manitoba soils have higher organic matter contents.

The amount of runoff generated during a rainstorm is influenced by antecedent soil moisture. Due to differences in climate, soil moisture content in Manitoba soils would be expected to be higher than in areas where the USLE was developed.

The crop management factor, C, proposed by Wischmeier (1960) also has limitations for application in Manitoba, since the information available is for species and growth stages common to the United States. Therefore, the same degree of soil protection may not be afforded by species and growth stages common to the Canadian Prairie conditions. Changing tillage practices and crop rotations will also affect surface residue cover, soil moisture which in turn affect surface runoff events. These factors need to be considered in evaluating C factor values for various crop management systems in Manitoba.

The current research has two main objectives. The long term objective

is to provide information on soil erosion due to rainfall necessary for making recommendations for soil conservation practices in Manitoba. The short term objective is to evaluate the soil erodibility factor, K, and the crop management factor C. The latter information would be used in achieving the long term objective.

MATERIALS AND METHODS

Field Experiments

Four field sites with different major soil types were chosen for the research. The first, on a Gretna clay near Miami, was established in the summer of 1984. The second, on a Leary sandy loam, near Roseisle, was established in the spring of 1985. The third, on a Ryerson loam, near Boissevain, was established in the summer of 1986. The fourth, on a Carroll clay loam, near Brandon, became operational in the spring of 1987.

Plot dimensions were 22.13 m long (up and down the slope) and 4.6 m wide, so chosen as to conform to the standard plot dimensions used during the development of the USLE. Four crop management treatments: 1) continuous fallow, 2) continuous conventional tillage wheat, 3) continuous corn, and 4) alfalfa, were selected for the experiments. Also, at the Ryerson loam and Carroll clay loam sites, a minimum tillage wheat treatment was added. Measurements for the 1986 growing season were obtained on the Gretna clay and Leary sandy loam sites. The Ryerson loam and Carroll clay loam sites became fully operational in the spring of 1987. Cultivars used were Rambler alfalfa, Columbus wheat and Pioneer 3995 corn. Seeding and fertilizing were done according to guidlines outlined in "Field Crop Recommendations for Manitoba". For weed control,'Embutox E,'' Hoegrass II,'' Attrex Plus' and Round Up were used.

Alfalfa was underseeded to wheat in the establishment year. Alfalfa seed was broadcast on the prepared seedbed and harrowed twice. Wheat was drill seeded on both conventional and minimum tillage treatments. Corn was hand planted. Row spacings for wheat and corn were 18 cm and 72 cm , respectively. Corn plots were row cultivated twice during the growing season. Summerfallow plots were cultivated every three to five weeks. All tillage operations were done up and down the slope in order to remove the conservation practice factor. Wheat was harvested at maturity for seed yield and corn at 65% whole plant moisture for total dry matter. The stubble remaining after harvest was 10-12 cm for wheat and 5-10 cm for corn. Other plant residues were removed after harvest.

Residue and crop cover measurements were made throughout the growing season. In spring, these were done by stretching a 5 m rope with ten evenly spaced marking, diagonally across the plot. The presence or absence of residue or plant part immediately below each mark was recorded. This method was replicated five times with twenty readings per sampling point on each treatment and % cover calculated. When the crop had grown to about 15 cm in height, the point-line method was used. This comprised of a horizontal bar with twenty evenly spaced markings supported on a stand above the crop canopy. Sighting down from each marking established the presence or absence of a plant part.

In this case, five replicate measurements were made on each treatment, and % cover calculated.

Runoff and sediment flowed into a trough at the downslope end of each plot. The sampling system consisted of a 15 cm high flume which directed runoff water onto a rotating Coshocton wheel. The sampling wheel was 30 cm in diameter and had on its surface an elevated slot along the radius of the wheel. Since the area of the slot was 1% of the surface area of the wheel, it sampled 1% of runoff and sediment every revolution. The wheels at the Gretna clay and Leary sandy loam sites were finned so that they were propelled by the runoff. Wheels at the Ryerson loam and Carroll clay loam sites were rotated by electric motors. Runoff and sediment sampled by the wheels were directed through tubing into removable collection containers. After each storm, the collection pails were exchanged and any soil deposited in the trough was collected. The samples were oven dried and weighed, and appropriate calculations made to determine the amount of soil loss from the various treatments for each storm.

Stilling wells, attached to the side of the flume, in which the float from a water level recorder was housed, permitted the runoff flow rate during a storm to be measured. Peak runoff rate for each storm was correlated with sediment loss in each cropping treatment.

Tipping bucket and standard rain gauges were installed a short distance form the plots at each site. Rainfall data extracted from the tipping bucket charts was used to calculate the rainfall erosivity factor, R. Total storm rainfall was compared to that measured by the standard rain guage. When there was a discrepancy between the two measurements, rainfall intensity data from a nearby weather station was used.

Antecedent soil moisture was measured on randomly spaced points on the upper, middle and lower slope positions of each treatment at depth of 0-7 and 7-15 cm. The average soil moisture content for each depth on each treamment was calculated.

Laboratory Analyses

Soil samples were taken in a grid pattern across each plot on each site. These were analysed for particle size distribution and organic matter content. Structure and permeability were estimated from soil survey reports. The data obtained was used in estimating the soil erodibility factor K from the USLE Nomograph. The K factor was also calculated from the equation proposed by Young and Mutchler (1977). The latter equation uses data from particle size analysis, bulk density, aggregate index, dispersion ratio and % montmorillonite clay in the soil. The estimated K values were compared to those obtained by field measurement.

Data Analysis

The design and management practices described for the experiment are expected to eliminate some of the factors in the USLE for the ease of calculations for the K and C values. The topographical factors (L and S) are numerically equal to 1.0 under the standard experimental conditions i.e. 22.3 x 4.6 m and the 9% uniform slope. The

conservation factor (P) also equals 1.0 under the upper slope cultivation practices used in the plots which eliminate conservation effects. The cropping management factor (C) under summerfallow conditions also equals 1.0.

The USLE less (L and S), (P) and (C) therefore becomes:

$$A = RK$$

where, A = soil loss from summerfallow
R = rainfall erosivity
K = soil erodibility

The experimental (K) is calculated as:

$$K = \frac{A \text{ (Soil loss from summerfallow)}}{R \text{ (rainfall erosivity)}}$$

The (C) factor values for each cropping management system is determined for different crop growth stages using the formula:

$$C = \frac{A \text{ (Soil loss from cropped plot)}}{A \text{ (Soil loss from summerfallow)}}$$

The obtained (K) value is compared with (K) estimated using the USLE Nomograph and the Young and Mutchler Equation (1977).

RESULTS AND DISCUSSION

The Gretna clay and Leary sandy loam sites were the only sites sampled during the growing season of 1986, since the Ryerson loam and the Carroll clay loam sites became operational in 1987. The four sites were all sampled during the growing season of 1987.

The pattern of soil loss rates from the various cropping treatments would be expected to conform with the loss from summerfallow > loss from conventional tillage wheat > loss from minimum tillage wheat > loss from alfalfa. The rates of soil loss recorded from the Gretna clay and Leary sandy loam sites for the 1986 growing season did not conform to this pattern. The soil losses recorded from the summerfallow treatment were not as high as would have been expected as compared to other treatments. (See Tables 1 and 2). This discrepancy may have been due to the periodic cultivation of the summerfallow, which may have contributed to high infiltration rates. This situation could have resulted in reduction of runoff generation and flow rates with consequent reduction of erosion under light rainstorms. The rainfall characteristics which affect runoff and related erosion rates are mainly rainfall duration and intensity. The generation of runoff during a rainstorm is closely related to the storm duration for a given intensity. A storm of short duration may not produce runoff whereas a storm of long duration will produce runoff since intense rainstorms will exceed the soil infiltration and water holding capacity by a greater margin than does a gentle rain. The recorded rainfall events for the 1986 growing season were mainly characterized by less erosive rainstorms. This could explain why the summerfallow did not erode as highly as would have been expected.

The conventional tillage wheat and corn cropping treatments recorded erosion rates higher than those recorded for summerfallow. This was possibly due to poor stand development during the early growth stages in the wheat plot. For the corn plot, upslope ridging along the corn rows tended to favour channelized flow with high runoff flow concentrations. Defoliation and trampling of corn plot by wildlife in the Leary sandy loam site could also have contributed to the high soil losses. Also, the wheat plot had to be reseeded to improve the stand. Poor germination rates resulting in a non-uniform growth pattern may not have provided an effective ground surface cover during the rainstorms. In addition, the runoff sampling wheel for these sites are runoff propelled and have been observed to undersample during light rainstorms due to deposition of sediment on the wheels that tend to make them turn more slowly.

The soil losses recorded for the four sites during the growing season of 1987 conform more closely with the expected pattern of soil loss among the various treatments. (See Tables 3, 4, 5 and 6.) This was probably due to some highly erosive rainfall events recorded during the growing season. The rainfall event on August 14 was the most catastrophic since for three sites the annual average R value for southern Manitoba, which is about 1000 MJ mm ha^{-1} h^{-1} was exceeded. The soil loss during this rainstorm was probably greater than the measured loss in some of the sites, due to the inadequacy of the collection capacity of the sampling system during the rainstorm. This shows that from time to time highly erosive rainstorms can occur, and cause high erosion rates, especially when the crop is at a stage when the ground surface cover is not sufficiently protective. The summerfallow cropping treatment recorded the highest erosion rates during these highly erosive rainstorms. This was because intense rainstorms may decrease infiltration rates by destruction of the soil structure with consequent sealing of soil surface. This will contribute to increased runoff flow rates that will intensify the soil erosion rates when the ground surface cover is inadequate or absent.

The total annual soil losses from all the sites conformed well with the expected pattern of soil loss. The same pattern was also observed with highly erosive individual rainstorms which recorded the highest erosion rates from the summerfallow treatment. The conventional tillage wheat treatment recorded higher erosion rates as compared to minimum tillage wheat treatment, especially in total annual soil losses (See Table 5 and 6). Some rainfall events recorded higher soil losses from the alfalfa and minimum tillage wheat cropping treatments, especially at the Ryerson loam site, where excavation by rodents tended to magnify the soil loss rates (See Table 5). The decreased rate of soil loss in minimum tillage wheat as compared to conventional tillage wheat could serve as an indication that, for conservation purposes, the minimum tillage farming practice would be most appropriate.

The influence of antecedent soil moisture on soil losses under different rainstorms is not very easy to assess since almost all rainstorms recorded occurred in a few days after the sampling for soil moisture was done. The soil moisture sampling was done on a routine (weekly) basis and the recorded soil moisture content may not necessarily represent the actual moisture content at the time the rainstorm occurred. The existing field situation makes it impossible to do this kind of sampling on timely basis.

The ground cover and final crop yields for all the sites were generally high and conformed well with the expected maximum cover for various cropping treatments except for corn (data not shown). This was mainly due to defoliation by wild life and poor stand development on some of the sites. The problem of defoliation by wildlife occurred at the Leary sandy loam site during the 1986 growing season, and the poor stand development occurred at the Carroll clay loam site in 1987.

The calculations for the measured soil erodibility (K) factor and the cropping management (C) factor values will be carried out using the already outlined data analysis procedures (see data analysis section). The obtained (K) value will be compared with those estimated using the soil physical analysis data as obtained by Wischmeier and Smith (1978) and Young and Mutchler (1977). The obtained (C) value will also be compared with those outlined by Wischmeier (1960). The observation made in the comparative aspects of the measured values and those obtained using the existing methods will determine if there is a need to modify these values or not.

CONCLUSION

(a) The soil losses recorded from various soil types and cropping management treatments under different rainfall events have been shown to be significant.

(b) The results obtained so far point out the need for long-term measurements of soil losses and the related erosion controlling factors so as to obtain an average applicable perspective of the measured factor values.

REFERENCES

Field crop recommendations for Manitoba, 1985. Manitoba Department of Agriculture.

Wischmeier, W.H., 1959. A rainfall erosion index for a universal soil loss equation. Soil Sci. Soc. Amer. Proc. 23:246-249.

Wischmeier, W H., 1960. Crop management factor evaluations for a universal soil loss equation. Soil Sci. Soc. Amer. Proc. 24:322-325.

Wischmeier, W.H., C.B. Johnson and B.V. Cross. 1971. A soil erodibility nomograph for farmland and construction sites. J. Soil and Water Conserv. 26:189-193.

Wischmeier, W.H. and Smith, D.D., 1978. Predicting rainfall erosion - a guide to conservation planning. U.S. Department of Agriculture, Agriculture Handbook No. 537.

Young, R.A. and Mutchler, C.K., 1977. Erodibility of some Minnesota soils. J. Soil and Water Conserv. 32:180-182.

Table 1. Rainfall characteristics, antecedent soil moisture and soil losses associated with major storms at the Leary sandy loam site, 1986.

Date	Antecedent Soil Moisture (% by weight)								Total Rainfall	Maximum 30 min Intensity	Rainfall Erosivity Factor R	Soil loss (T/ha) from			
month, day	alfalfa 0-7	alfalfa 7-15	wheat 0-7	wheat 7-15	corn 0-7	corn 7-15	fallow 0-7	fallow 7-15	(mm)	(mm/h)	(MJ mm ha^{-1} h^{-1})	alfalfa	wheat	corn	fallow
4 30	-	-	-	-	-	-	-	-	19.0	2.40	13.77	0.01	0.00	0.01	0.00
5 6	-	-	-	-	-	-	-	-	54.2	10.87	214.00	0.18	20.76	11.55	10.46
6 14	5.9	6.4	8.2	15.9	9.9	15.8	8.4	13.0	42.4	18.00	326.15	0.05	0.38	9.42	0.28
6 20	10.4	10.8	9.8	12.2	10.2	13.1	9.2	12.8	21.2	14.40	140.70	0.03	1.27	12.90	1.42
7 3	13.8	14.5	8.9	11.6	14.0	14.9	8.9	13.3	12.0	12.00	83.15	0.00	28.85	10.00	0.07
7 10	7.3	8.7	6.1	8.0	9.8	11.9	9.2	11.7	58.0	5.00	99.25	0.01	0.47	0.35	0.25
9 25	7.5	6.7	7.7	8.5	9.0	9.5	8.8	11.2	24.2	5.20	49.58	0.00	24.90	12.41	0.17
9 29	13.0	11.9	11.8	12.7	12.4	12.3	15.5	13.1	19.3	2.40	14.83	0.00	0.06	0.00	0.02
Annual total											941.43	0.29	76.69	56.63	12.67

Table 2. Rainfall characteristics, antecedent soil moisture and soil losses associated with major storms at the Gretna clay site, 1986.

Date	Antecedent Soil Moisture at depth (cm) (% by weight)								Total Rainfall	Maximum 30 min Intensity	Rainfall Erosivity Factor R	Soil loss (T/ha) from			
month, day	alfalfa 0-7	alfalfa 7-15	wheat 0-7	wheat 7-15	corn 0-7	corn 7-15	fallow 0-7	fallow 7-15	(mm)	(mm/h)	(MJ mm ha^{-1} h^{-1})	alfalfa	wheat	corn	fallow
5 6	17.3	23.2	22.7	25.1	22.3	31.5	21.0	25.6	55.2	16.7	392.3	0.47	12.32	7.63	12.04
6 20	17.3	17.2	23.4	24.0	21.7	22.9	20.8	22.3	21.6	14.4	142.6	2.74	0.12	0.15	0.10
7 3	17.1	17.0	22.3	22.3	21.0	23.7	22.3	22.5	27.0	19.0	254.0	0.06	15.70	35.56	16.30
7 10	17.8	16.5	22.8	24.4	23.7	25.7	24.0	24.9	22.0	3.9	28.9	0.01	1.65	0.35	3.70
9 25	11.1	12.6	10.8	14.6	10.6	16.8	17.6	20.3	24.6	12.4	135.2	0.01	0.05	0.04	0.00
9 29	25.0	21.3	24.6	18.3	24.3	18.6	28.1	21.7	13.0	4.0	16.2	0.04	0.01	0.01	0.01
Annual total											969.35	3.33	29.85	43.74	32.15

Table 3. Rainfall characteristics, antecedent soil moisture and soil losses associated with major storms at the Gretna clay site, 1987.

Date	Antecedent Soil Moisture at depth (cm) (% by weight)								Total Rainfall	Maximum 30 min Intensity	Rainfall Erosivity Factor R	Soil loss (T/ha) from			
	alfalfa		wheat		corn		fallow								
month, day	0-7	7-15	0-7	7-15	0-7	7-15	0-7	7-15	(mm)	(mm/h)	(MJ mm ha^{-1} h^{-1})	alfalfa	wheat	corn	fallow
7 3	15.5	14.5	14.6	18.1	14.4	19.8	13.2	21.4	13.0	7.6	18.66	-	5.56	0.04	0.09
7 10	13.9	13.4	15.6	16.7	18.8	20.3	19.6	23.6	55.8	31.4	392.23	0.01	0.12	3.93	4.02
7 20	28.1	27.8	26.1	18.9	27.9	28.1	28.3	28.3	42.2	10.3	77.33	0.00	0.08	0.93	0.30
7 24	20.3	22.6	18.0	24.7	21.6	26.0	26.3	20.6	13.2	10.0	26.73	-	0.80	0.05	7.28
8 14	15.8	18.5	18.1	22.7	19.4	21.2	22.9	22.9	73.8	80.0	1422.67	0.01	0.45	1.09	214.19
9 29	17.3	16.0	23.4	23.3	20.7	19.9	20.9	25.2	15.8	6.7	16.69	-	0.01	2.44	0.06
Annual total											1954.31	0.02	7.02	8.48	225.94

Table 4. Rainfall characteristics, antecedent soil moisture and soil losses associated with major storm events for Leary sandy loam site, 1987.

Date	Antecedent Soil Moisture at depth (cm) (% by weight)								Total Rainfall	Maximum 30 min Intensity	Rainfall Erosivity Factor R	Soil loss (T/ha) from			
	alfalfa		wheat		corn		fallow								
month, day	0-7	7-15	0-7	7-15	0-7	7-15	0-7	7-15	(mm)	(mm/h)	(MJ mm ha^{-1} h^{-1})	alfalfa	wheat	corn	fallow
5 21	6.4	6.8	8.91	14.3	11.4	13.1	9.8	12.7	27.4	3.1	12.62	-	0.05	0.04	0.03
6 24	5.5	7.1	5.6	6.6	9.1	12.2	9.5	13.1	22.2	11.2	44.90	-	0.04	0.05	0.07
7 3	7.9	8.2	8.4	8.1	10.0	10.9	10.1	12.2	18.8	10.3	38.13	-	0.04	0.04	5.17
7 10	6.3	5.8	6.9	6.8	10.8	9.4	10.0	11.8	16.0	8.0	21.02	0.00	0.01	0.01	0.01
7 20	9.8	9.1	9.4	10.6	11.5	11.6	11.4	10.4	51.4	14.4	140.2	-	0.01	0.03	0.03
8 14	11.7	6.5	12.1	8.3	13.1	7.8	12.9	10.6	96.8	48.3	1006.08	0.00	0.14	1.76	108.3
9 29	14.4	6.9	8.5	11.5	6.4	8.7	9.0	12.1	40.2	12.0	89.41	-	0.01	0.02	0.02
Annual total											1352.36	0.00	0.30	1.95	113.63

Table 5. Rainfall characteristics, antecedent soil moisture and soil losses associated with major storms at the Ryerson loam site for 1987.

Date	Antecedent Soil Moisture at depth (cm) (% by weight)										Total Rainfall	Maximum 30 min	Rainfall Erosivity	Soil loss (T/ha) from				
			conv till		min till										conv	min		
month, day	alfalfa 0-7	alfalfa 7-15	wheat 0-7	wheat 7-15	wheat 0-7	wheat 7-15	corn 0-7	corn 7-15	fallow 0-7	fallow 7-15	(mm)	Intensity (mm/h)	Factor R (MJ mm ha^{-1} h^{-1})	alfalfa	wheat	wheat	corn	fallow
6 2	9.8	11.7	30.8	13.8	23.0	21.3	20.5	19.4	20.6	21.4	27.6	31.2	211.63	0.04	0.08	0.09	0.09	0.06
6 24	10.0	11.0	10.8	13.5	14.1	16.6	15.9	21.0	14.5	19.5	25.1	20.8	100.37	0.06	0.08	0.07	0.04	0.03
7 8	14.5	11.2	16.0	13.2	15.4	11.6	18.7	18.1	17.6	19.9	34.8	30.0	232.48	0.03	0.04	0.04	0.04	0.05
7 10	17.2	13.9	17.2	13.9	17.7	16.8	19.8	18.9	29.9	21.7	27.8	8.0	42.46	0.01	0.02	0.03	0.02	0.02
7 20	15.3	15.1	14.4	16.8	16.9	18.5	18.3	20.8	16.6	21.8	68.4	20.0	275.47	0.00	0.01	0.01	0.01	0.01
7 31	11.9	12.8	11.6	14.5	11.4	16.9	15.3	16.9	17.2	19.3	37.5	8.8	62.91	-	0.01	0.01	0.01	0.01
8 4	15.4	16.3	16.4	19.6	10.9	20.1	20.0	20.4	15.7	24.3	37.8	69.6	722.23	0.00	2.28	0.05	0.60	0.39
8 14	10.1	11.1	12.4	14.9	11.8	16.2	12.0	15.9	15.4	19.8	119.4	52.0	1429.01	0.15	0.79	0.97	12.21	14.73
Annual total													3076.56	0.30	3.26	1.26	13.03	15.31

Table 6. Rainfall characteristics, antecedent soil moisture and soil losses associated with major storms at the Carroll clay loam site for 1987.

Date	Antecedent Soil Moisture at depth (cm) (% by weight)										Total Rainfall	Maximum 30 min	Rainfall Erosivity	Soil loss (T/ha) from				
			conv till		min till										conv	min		
month, day	alfalfa 0-7	alfalfa 7-15	wheat 0-7	wheat 7-15	wheat 0-7	wheat 7-15	corn 0-7	corn 7-15	fallow 0-7	fallow 7-15	(mm)	Intensity (mm/h)	Factor R (MJ mm ha^{-1} h^{-1})	alfalfa	wheat	wheat	corn	fallow
6 3	22.2	26.0	22.3	25.0	22.2	26.0	21.7	22.9	22.4	27.5	18.6	22.8	95.74	0.01	0.02	0.03	0.02	0.02
7 14	13.0	15.9	16.3	15.4	12.4	15.3	17.1	21.9	19.1	25.2	22.0	13.3	[illegible]	[illegible]	0.01	0.01	0.01	0.01
7 20	31.3	22.4	31.5	21.8	30.1	20.2	36.3	26.6	34.6	29.2	94.0	10.0	[illegible]	[illegible]	0.01	0.02	0.02	0.03
7 31	12.5	17.8	13.9	17.9	15.4	18.7	15.6	22.0	18.2	26.5	29.0	9.3	52.70	0.01	0.00	0.01	0.01	0.01
8 12	16.7	18.5	13.6	15.8	14.4	15.5	18.1	23.3	19.7	27.6	35.6	27.2	227.10	0.09	0.08	0.06	0.55	0.22
8 14	24.5	17.3	25.2	18.0	25.0	21.0	24.0	23.2	25.2	27.4	126.6	24.6	715.22	0.04	0.43	0.21	0.12	0.32
Annual total													1303.18	0.19	0.55	0.33	0.74	0.61

AGROMETEOROLOGICAL BULLETINS FOR THE PRAIRIES

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1. Introduction

Agrometeorological information packages can be categorized as:

i) Farm Weather Forecasts - These are forecasts which include parameters that are applicable to selected agricultural crops or farming practices. The rural format for Public Forecasts, introduced by Environment Canada in 1985, is an example of this type of information.

ii) Agroclimatological Booklets - The probability or risk of occurrence of specific climatic events is provided based on an analysis of historical weather records. An example is the Manitoba Agriculture publication, "Southern Manitoba's Climate and Agriculture" (Dunlop and Shaykewich, 1982).

iii) Agrometeorological Bulletins - The current growing-season's weather is monitored in near real-time to provide, via simulations, proxy data for the growth stage and moisture stress of selected crops, for the phenology of specific insects and for other production related phenomena. A set of five Prairie-wide bulletins was introduced, on an experimental basis, by Environment Canada in 1987.

iv) Agrometeorological Advisories - Specific advice about emerging or anticipated agricultural problems is offered to farmers based on a consideration of biological survey data and proxy data from biometeorological simulations. Manitoba Agriculture and Environment Canada have an on-going joint initiative to develop this type of service.

Thus, it can be seen that Agrometeorological Bulletins are just one component of a comprehensive agricultural weather service. However, they may be the most important component. They allow an assessment of the current growing-season against the yard-stick of climatic risk and they are a major building-block for agrometeorological advisories.

This paper briefly describes the content and availability of Environment Canada's Agrometeorological Bulletins for the Prairies. The "generic-model" used to transform the raw weather data into proxy agricultural data is outlined.

2. Agrometeorological Bulletins

A package of five Prairie-wide Agrometeorological Bulletins was produced on a weekly basis throughout the 1987 growing season. The Bulletins were distributed to a cross-section of government agencies and agri-businesses for evaluation. Each member of the targetted group has a requirement to monitor crop growth and vitality. Applications range from yield forecasting for processing, marketing or equipment sales, to integrated pest management, to the provision of agricultural advice.

A regular Bulletin was produced for each of the four major classes of Prairie crops - cereals (wheat), oil seeds (canola), row crops (corn) and perennial forages (alfalfa). The fifth Bulletin was tuned to insect phenology and the moisture status of fallow. Each Bulletin listed weekly totals and season-to-date accumulations with normals of an appropriate heat unit and rainfall. Weekly potential evapotranspiration values were calculated from the daily maximum and minimum temperatures and the solar radiation incident at the top of the atmosphere (Baier and Robertson, 1965; Baier, 1971). Potential evapotranspiration was converted to actual evapotranspiration using crop-specific consumptive-use curves (Dunlop, 1981; Morrison, 1987) and a root-zone soil drying function (Johnstone and Louie, 1984). Water-balance accounting procedures were followed. The "generic model", applicable to all the Bulletins, is outlined, Figure 1.

All of the synoptic, daily and weekly reporting sites, grouped by Crop District, in the agricultural areas of Manitoba (34 sites), Saskatchewan (58 sites), Alberta (40 sites) and Northwestern Ontario (5 sites) were listed on the Bulletins. The one exception was the row crop (corn) bulletin which only covered Manitoba. Site specific available water holding capacities (DeJong, 1987) plus site and crop specific planting dates were employed.

The Bulletins were available in tabular form via the mail and via dial-in computer-access. An example Bulletin is shown, Figure 2.

3. Future Developments

The Agrometeorological Bulletins were generally well received in 1987. Therefore, they will be issued again during the 1988 growing season. In 1989, they will be moved from the "experimental" to the "special product" category and be sold on a subscription basis.

Changes for 1988 will include the replacement of the weekly heat-unit column on each Bulletin by a "moisture stress" term - the difference between the available moisture and the crop's water demand. A Bulletin for barley will be added to the package and selected parameters may be available in chart form. In addition, Agrometeorological Outlooks, assuming normal future weather, may be developed.

References

1. Baier, W. and G.W. Robertson, 1965: Estimation of latent evaporation from simple weather observations, Can. J. Plant Sci., 45, pp. 276-284.

2. Baier, W., 1971: Evaluation of Latent Evaporation Estimates and their Conversion to Potential Evaporation, Can. J. Plant Sci., 51, pp. 255-266.

3. DeJong, R., 1987: Available Water Holding Capacity Maps of Alberta, Saskatchewan and Manitoba, Agriculture Canada.

4. Dunlop, S., 1981: An Agroclimatology of Southern Manitoba, Thesis, University of Manitoba, Department of Geography, Winnipeg, 109 pp.

5. Dunlop, S., and C.F. Shaykewich, 1982: Southern Manitoba's Climate and Agriculture, Manitoba Agriculture.

6. Johnstone, K.J. and P.Y.T. Louie, 1984: An Operational Water Budget for Climate Monitoring, CCC, Report No. 84-3, 52 pp.

7. Morrison, M., 1987: Growing Degree-Days and Canola Growth-Stages, (unpublished), Department of Soil Science, University of Manitoba.

Figure 1

AGROMETEOROLOGICAL BULLETINS

Generic Model

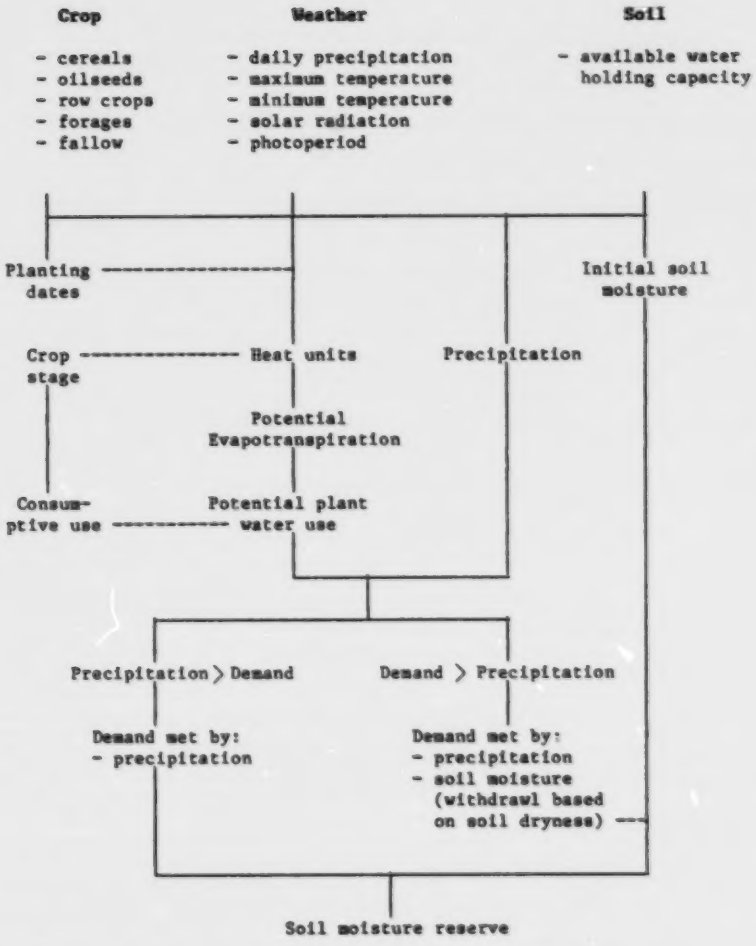

Figure 2

Environment Canada - (AES)

Agrometeorological Bulletin
For Cereal Crops
Biometeorological-Time and Moisture Status

For the period Jul. 27 to Aug. 2, 1987

Crop Dst	Location	Period BMT	Period PCPN	Period ET	Date Planted	Season-to-Date BMT (%N)	Season-to-Date PCPN (%N)	Season-to-Date Soil (%C)
	MANITOBA							
1	Turtle Mtn.	.86	36.6	11.7	May 3	5.7(122)	242(114)	122(61)
	Pierson	.82	12.6	12.1	May 3	5.6(122)	215(118)	82(41)
2	Brandon	.75	25.2	14.7	May 3	5.1(112)	201(101)	82(49)
	Cypress River	.80	12.8	10.4	May 3	5.8(121)	228(105)	98(43)
	Virden	.82	29.0	13.4	May 3	5.5(116)	243(129)	94(60)
3	Birtle	.71	14.6	17.7	May 10	4.7(114)	211(110)	59(48)
	Neepawa Water	.79	143.6	18.3	May 10	5.1(111)	342(177)	147(93)
	Oakner	.79	22.0	21.9	May 10	4.9(117)	254(140)	80(55)
4	Rossburn	.40	8.4	16.1	May 10	4.2(98)	160(77)	38(26)
	Russell	.72	12.2	17.9	May 10	4.7(115)	200(123)	54(39)
5	Swan River	.81	3.0	24.0	May 10	4.9(114)	306(171)	119(76)
	The Pas	.45	15.4	12.7	May 17	4.2(108)	146(92)	24(13)
6	Dauphin	.70	1.5	16.7	May 10	4.7(112)	159(85)	75(38)
7	Gladstone S.	.74	66.4	15.7	May 10	5.3(112)	251(136)	137(68)
	Grass River	.78	4.6	15.3	May 10	5.2(115)	204(117)	66(30)
	Portage Man.	.85	13.2	12.2	May 10	5.4(114)	184(90)	79(48)
	Starbuck	.79	6.6	11.4	Apr 26	5.6(110)	214(91)	95(37)
8	Altona	.84	4.6	11.3	Apr 26	6.4(118)	262(118)	143(56)
	Baldur	.78	28.0	8.3	Apr 26	5.9(123)	219(92)	69(48)
	Deerwood	.82	12.7	10.9	Apr 26	6.4(123)	232(89)	131(57)
	Emerson	.86	6.3	11.5	Apr 26	6.2(114)	279(118)	142(59)
	Graysville	.83	12.0	10.9	Apr 26	5.9(120)	246(114)	118(57)
	Morden CDA	.89	5.4	11.0	Apr 26	6.9(128)	256(111)	151(68)
	Morris	.81	7.0	11.2	Apr 26	6.3(118)	274(122)	144(50)
	Plum Coulee	.88	4.8	12.0	Apr 26	6.6(121)	259(108)	120(66)
9	Steinbach	.85	2.0	11.4	Apr 26	6.1(121)	281(123)	112(52)
	Winnipeg	.86	29.9	9.6	Apr 26	6.2(123)	217(92)	131(54)
	Pilot Mound 2	.86	8.0	8.6	Apr 26	6.2(135)	219(95)	88(41)
10	Pinawa WNRE	.77	33.2	15.5	May 3	5.3(120)	229(102)	101(55)
	Sprague	.82	2.2	15.5	May 3	5.4(123)	264(113)	67(46)
	Bissett	.73	5.6	28.4	May 10	4.8(114)	279(135)	164(69)
11	Stony Mountain	.82	19.8	9.4	May 3	5.7(115)	188(99)	78(37)
12	Broad Valley	.77	12.8	16.4	May 10	5.2(126)	201(113)	74(31)
	Gimli	.81	38.6	17.7	May 10	5.0(114)	208(111)	103(51)

BMT - Biometeorological-Time
- Season-to-date BMT for wheat
0 - planting 1 - emergence 2 - jointing
3 - heading 4 - soft dough 5 - ripe

PCPN - Precipitation (mm)
ET - Estimated evapotranspiration (mm) for wheat
SOIL - Modelled soil moisture reserve (mm)
%N - Percent of normal
%C - Percent of capacity

Normals used in percentage calculations are for the period 1951-1980.

DAUPHIN CROP CLUB

PRODUCTION AND ECONOMICS

K. Watson

The Dauphin Crop Management Club began in 1985 under the sponsorship of the Dauphin Agricultural Society with partial funding through the Agrifood Program.

During this paper I hope to acquaint you with some of the activities and observations to date within the club.

Producer membership the first year was eleven(11), with twenty-eight (28) each for the next two years.

The objective of the Club is to observe, analyze, record,evaluate and discuss the various factors that influence crop production in the local area. The bottom line is managing the inputs for not necessarily the highest yield, but the highest economic net return.

All types of Crops(wheat, barley, oats, canola, flax, peas, lentils fababeans, red clover) have been grown on the Club fields.

The Club member picks and uses the same 40 acre field each year. Cropping decisions are used that they feel will give them the highest net return per acre.

Each year the Club has a Summer Tour to visit the majority of fields so the yield and return discussions are easier to relate to during the winter months. Three to Four other meetings are held during the winter to discuss the years cropping and other topics of current interest.

The Club has been involved in other Projects such as Bus Trips to the Weed Fair in Brandon, Training Sessions such as Farm Accounting with Computers and Grain Marketing.

The records of the club member fields are recorded and calculated by use of the micro computer. We

have developed a program to record and calculate the members own inputs and costs. Custom rate are charges used to calculate machinery charges.

The end result is to develop an analysis to give the final profit of the Producers Crop Management Plan.

To help evaluate and make the program meaningful, the Club has a weigh wagon. The unit is large enough to handle any size truck or combine. Harvesting downtime in the field is minimal. Yields are taken from selected swaths that represent 2-5 acres across the field.

Members are encourage to try altering different inputs that are of particular concern to them. A comparison yield is then easily taken at harvest with the weigh wagon.

The most common and easiest input to alter is fertilizer rates. One example addressed the concerned about the loss of Nitrogen between Spring and Fall application. 80 Lb. Actual NH_3 was applied in both Spring and Fall. The yield difference this fall was 1.7 bushels per acre of Wheat or 4.6% higher yield from Spring applied product.

The Club is also interested , and working with WESTCO on some Fertilizer placement and potassium research trials in the area.

In 1986 fungicides were used on 4 fields of wheat and one barley.

The wheat fields all showed positive yield increases of 2 to 8 bushels per acre. The zero till field showed the lowest yield increase. The yield increase was not economic considering the price of wheat and the cost of the product.

In 1987 no fungicides were used because crops were suffering from poor and staggered germination and were very poor with no disease present at the proper application time.

This year two fields were treated with the seed moisturizing process which is supposed to enhance germination.

There was a small yield increase in Wheat(1.3 bushel/acre) and Canola(1.1 bushel/acre).

Now for some bare economic facts.....

In 1986 with an average of 40 bushel/acre yield of hard red wheat, the average net return was -$12.54 per acre. All net return figures used do not include an allowance for living.

In 1986 barley showed a loss of $-39.23 per acre with an average yield of 68 bu/acre.

1986 Canola almost broke even at -4.51.

In 1986 flax was the best oilseed showing good average yield of 31 bu/acre and an average positive net return of $31.02. bu/ac.

Fababeans and peas showed the highest net returns.

Input dollars are of a great concern. We see the major input dollars in wheat going to fertilizer and chemical(34%). Overhead costs in land and machinery cannot be overlooked as they contribute to 47% of the total costs. Most other crops reflect this type of split.

Costs such as operating interest and fuel have received a lot of attention but as they each make up about 3% of the total input costs. Have we put too much emphasis on these?

Pulse crops e.g. Fababeans change cost emphasis as expected with the major costs on seed and chemicals(41%) rather than fertilizer.

1987 showed the average wheat yields dropped from 39.8 to 33.3 bu/acre, 6.5 bu/acre or 16% drop from 1986. This was mainly due to dry soil conditions in the spring, uneven germination and regrowth of weeds.

This year wheat is showing on average a net return of -$39.09 down -$27.17 from last year. Remember living costs still have to come from this return. It does help justify the WGSA and Special Grains Program I think.

The highest net return was from a field of fababeans recording a net yield of 3868 lb./acre to give a net return of $116.04 per acre.

TARGET YIELDS

Some of the other benefits from the program is to apply and evaluate things like target yields in a practical manner in field situations.

In 1986 the target yields predictions for wheat proved to be 5% lower than the actual yields measured in the field.

In 1987 the target yield predictions for wheat proved to be 25.4% higher than the Actual field observations.

1987 had a dry spring with uneven germination and suffered later weed competition from regrowth. The soil types all receive the target yield recommendations based on the moist soil category.

For the two year(1986-87) average of 17 fields the the target yield predictions are 6.8% higher than the actual yields measured in the field.

The soil test lab, I believe, suggests 10-15% accuracy under normal average conditions.

With another couple of years observations, it appears we should be able to help reconfirm the accuracy and use of the Target Yield Program for the producers crop management decisions.

In summary, the Dauphin Crops Club is proving to be an excellent extension program. It is allowing the producers to locally observe, evaluate, demonstrate and share many of the crop production methods. The technology and experience shared will help the producers attain the highest net economic return.

HABITAT ENHANCEMENT LAND USE PROGRAM
(HELP)

The Prairie Pothole Region of the Northern Great Plains of North America lies within the Aspen Parkland Biome, a zone transition between the prairies and deciduous forest. The area is characterized by a distinctive rolling topography formed by ancient glaciers, with millions of small wetlands. These wetlands form a complex system that because of high soil productivity, periodic natural draw-downs, and a warm summer climate supports a rich diversity of animal and plant life. With less than 5% of North America's area, the prairie pothole district produces 75% of its duck population.

The same rich soils and warm summer climate have attracted an agricultural industry that has competed with wildlife for space. Agriculture encroachment in the form of: clearing and filling, draining, and burning has produced widespread damage to wetland and upland habitats in that region.

Agricultural "improvement" of these areas often has turned a landscape with abundant potholes into landscape that has been drained and used to grow grain. There is very little room for wildlife once this has been done. Along the way serious land use problems have become evident such as salinization, water erosion, wind erosion and wasted resources for both farmers and wildlife.

Landowners spend much time and money draining a prairie pothole, but instead of getting more cultivatable land, salinity spreads because the natural salt-controlling wetland vegetation is removed. Not only do salts spread to existing cropland decreasing its productivity but valuable wildlife habitat also is lost.

Wetlands are one of our most under-rated natural resources:

a) they store floodwaters
b) stabilize streamflows
c) purify runoff
d) absorb pollutants
e) recharge groundwater
f) trap silt
g) help control salinity
h) provide livestock with water and hay
i) reduce water erosion
j) produce waterfowl and furbearers
k) have considerable aesthetic value
l) supply fish farming sites
m) provide recreation areas

Most of the benefits of wetlands accrue to society but costs, such as decreased field operation efficiency and crop flooding, are borne by the farmer.

Encroachment of wetlands in the prairie pothole district of Manitoba has resulted in a 70% reduction of waterfowl habitat this century.

Since this area produces a large proportion of North America's waterfowl resource, great concern has arisen over the future of prairie duck populations. With a conservative estimate of the capital value of the resource to Canada's economy of over one billion dollars, we readily can see the significance of this habitat loss.

At the same time, concern for our dwindling soil resources has grown, especially since the senate released "Soil at Risk - Canada's Eroding Future". We have realized that if we do not do something soon, two irreplaceable Canadian resources, our soil and our waterfowl, will be no more.

It was these concerns that led to the development of The Manitoba Habitat Enhancement Land Use Program. It was clear right from the start that a single purpose program would have little chance of success.

Objectives were set to have the widest possible benefits to agriculture, wildlife, and society:

1) To HELP foster co-operation between wildlife and agriculture.

2) To HELP stem the annual loss of 50 square miles of wetlands in Manitoba.

3) To HELP promote sound land-use practices for soil, water, and wildlife conservation.

Six different agencies co-operated in its inception and presently oversee the program through a Steering Committee with representatives from each. These six agencies are:

a) Manitoba Department of Natural Resources
b) Wildlife Habitat Canada
c) Ducks Unlimited Canada
d) Canadian Wildlife Service
e) Manitoba Department of Agriculture
f) Manitoba Wildlife Federation

In planning this pilot project, we made extensive use of the expertise of others such as the United States Soil Conservation Service, North Dakota Game and Fish Department, The U.S. Fish and Wildlife Service, Mid Continent Waterfowl Management Project in Minnesota, and the Alberta Fish and Wildlife's Red Deer County Program. Their experiences in managing wildlife and conserving soil on private lands were invaluable in our planning the Manitoba Help Pilot.

We also undertook a landowner attitude survey in Manitoba's Pothole District that identified the potential program options with the most promise.

The Manitoba Habitat Enhancement Land Use Program will be operational in 1987, the Rural Municipality of Shoal Lake, in the heart of the Province's pothole district. A Local Advisory Committee comprised of 4 conservation-minded farmers, 2 of which are municipal councillors, plus the area agricultural representative and Natural Resource Officer, has worked closely with us to ensure the suitability of various program options to the project area. The Local Advisory Committee's input, along with that of the R.M. Council has been a key factor in HELP's broad base of support.

Co-operators in the program will be able to choose from a wide range of options designed to maximize the benefit to soil, wildlife, and agriculture. For example, leasing blocks of wetlands and surrounding native prairie provides income to farmers with idle pasture on marginal lands that they might otherwise be forced to break to realize some income. These pastures often are the least productive farmlands remaining in the area, and may be subject to erosion or salinization if broken. Leasing these areas benefits the farmer by increasing his income, prevents land degradation, and secures important wildlife habitat. Similar leasing options include planting salinity barriers around potholes to provide protection for surrounding cultivated fields and waterfowl nesting cover, planting soil-building grass-legume mixtures on erosion prone soils, and setting aside areas of presently cultivated, hayed, or pastured lands for nesting cover. Payment rates will vary depending upon the lands agricultural potential, and will reflect cash rental rates for the area.

Other HELP conservation farming options include:

a) Winter Wheat production/minimum or zero tillage
b) Rotational grazing

The landowner will be an integral part of the management of these lands. His expertise and equipment will be used to make most efficient use of limited staff time and resources, have the farmer feel a necessary part of the management team, and possibly influence his adoption of techniques on non-project lands.

Additional options such as donating habitat, erecting yard signs, purchasing key areas, and improvement of secure habitat through management, allow for a great degree of flexibility in the program.

We aim to set aside 1200 ha (3000 ac) of habitat per year, plus influence land use decisions of another 1200 ha (3000 ac) annually.

Expansion into adjoining municipalities is anticipated by 1988. Feedback from landowners and the Local Advisory Committee will help us ensure the program meets the dual goals of benefitting wildlife and agriculture.

Thus, by having a payment scheme that provides the farmer with a fair return on his investment in land, allowing for significant ongoing local input, and providing land management alternatives that have important soil, water, and wildlife conservation benefits, the Manitoba Habitat Enhancement Land Use Program will set the stage for a province-wide integrated approach to land, water, and wildlife resource management into the 21st century.

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THE ROLE OF SOIL ORGANIC MATTER IN REDUCING SOIL EROSION AND ENHANCING SOIL FERTILITY

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A. INTRODUCTION

The occurrence of organic matter in almost every soil is well known Soil organic matter (SOM) consists of a mixture of plant and animal products in various stages of decomposition and substances synthesized from the breakdown products.

The SOM is usually divided into two groups (Choudhry 1984, Stevenson 1982, Schnitzer and Khan 1972):

(i) nonhumic substances (non-HSs)
(ii) humic substances (HSs)

Non-HSs include a large number of compounds of well-known structures including:

- carbohydrates
- proteins, peptides
- amino acids
- fats
- waxes, resins
- pigments
- other low-molecular-weight organic substances

Based on their solubility in alkali and acid, soil HSs are commonly divided into three major fractions, namely (Choudhry 1984, Stevenson 1982, Schnitzer and Khan 1972):

I. fulvic acids (FAs)
II. humic acids (HAs)
III. humins

The bulk of SOM consists of HSs.

In order to find out whether SOM plays an important role in the reduction of soil erosion together with the enhancement of soil fertility resulting in sustained crop production, an extensive computer search of the literature was conducted using the commercially available services of INET 2000. Chemical Abstracts, CA (from July 1973 to Nov. 1987) and Commonwealth Agricultural Bureux, CAB (from 1972 to Oct. 1987) were utilized as data bases. For the literature search, eighty-three sets were used.

This review presentation includes discussions of the literature providing evidence to support the role of SOM in sustained agricultural yields through:

I. Enhancement of soil fertility
II. Enhancement of soil aggregate stability
III. Reduction of soil erosion
IV. The effects of pesticides

B. SOIL FERTILITY

Changes in soil fertility caused by various organic and N-fertilizer amendments have been studied by Schnurer and associates (1985) in a long-term field trial involving cropping largely with cereals. Table 1 indicates biomass C determined from direct counts and from the

Table 1. Calculated values for C and N contents of microbial biomass. The combined biomass of bacterial, fungi and protozoa is given under "direct counts". Biomass C (method A and B) and N by the fumigation method is calculated as described in the text. All values are given as μg C or μg N g^{-1} dry wt (mean values ± SE, n = 4). (Reproduced from Schnurer et al. 1985.)

	Biomass C			Biomass N
Treatment*	Direct Counts	$CHCl_3$ Fumigation (A)	$CHCl_3$ Fumigation (B)	$CHCl_3$ Fumigation
I (fallow)	378 ± 65	158 ± 11	230 ± 10	48 ± 3
II (no addition)	653 ± 124	203 ± 10	313 ± 10	58 ± 5
III (+N)	815 ± 115	276 ± 20	397 ± 9	76 ± 2
IV (straw + N)	2264 ± 268	317 ± 43	604 ± 18	118 ± 2
V (manure)	1571 ± 173	340 ± 15	584 ± 8	117 ± 5
Correlation with loss on ignition	r=0.63**	r=0.74***	r=0.83***	r=0.85***

***P <0.001, **P <0.001
*N-fertilizer was $Ca(NO_3)_2$ (80 kg N ha^{-1} yr^{-1})

amounts of CO_2-C evolved from the fumigated sample with (see Columns 3) or without (Column 4) substraction of CO_2-C from unfumigated sample. This table also includes biomass N. The five treatments (see Table 1) resulted in SOM ranging from 4.3% (I) to 5.8% (V). Biomass-C showed a positive correlation with SOM. However, biomass-N was highest in the straw +N treatment (IV) and lowest in the fallow soil (treatment I).

Foster (1980) investigated the influence of SOM on soil fertility as expressed by the millet and maize crop yields in the absence and presence of N and P fertilizers. About 900 trials were carried

out on private farms in Uganda. Performance of the cereals in individual trials could not be related to soil propoerties. However, average yields of finger millet and responses to N and P fertilizers at different centres possessing ferrallitic soils were correlated with the average soil organic matter levels. Likewise, when the variable influence of weather was suppressed by considering only mean yield determined in each season at each centre, millet yields obtained without fertilizer were very significantly related to mean SOM (soil organic matter) levels (see Figure 1).

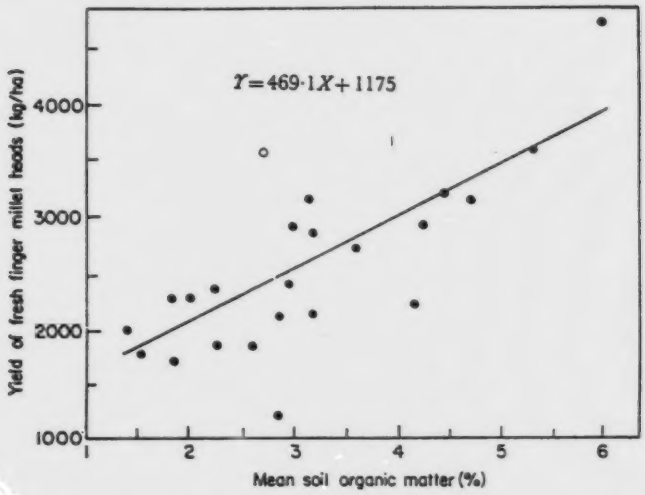


Figure 1. Mean yield of fresh finger millet heads in the absence of fertilizer in each season at each centre in relation to mean soil organic matter levels. O, anomalous data for Abako (1967). X represents soil organic matter content (%). The values of R^2 and residual error amounted to 55.6% and 523, respectively. (Reproduced from Foster (1980).)

Recently, Sah and Mikkelsen (1986) reported the results of a study covering the effects of anaerobic decomposition of organic matter on sorption and transformations of phosphate in both unflooded and flooded soils. Figure 2 shows the influences of soil flooding with or without added cellulosic organic matter (OM) on phosphorus (P) sorption at 30 μg/ml external P concentration (Pe). This figure indicates that the soil flooding, even without added OM, increased P sorption significantly over the unflooded soils. The added OM during flooding, however, further significantly raised P sorption values in drained soils (Figure 2). The values of the total organic carbon (TOC) of the Sacramento, Stockton, Meyers, and Willows, California (USA) soils were 1.94, 1.27, 0.78 and 1.38%, respectively.

Moreover, Ofer and coworkers (1982) investigated the nitrogenous constituents such as HSs (FAs and HAs), amino acids, nitrates, and

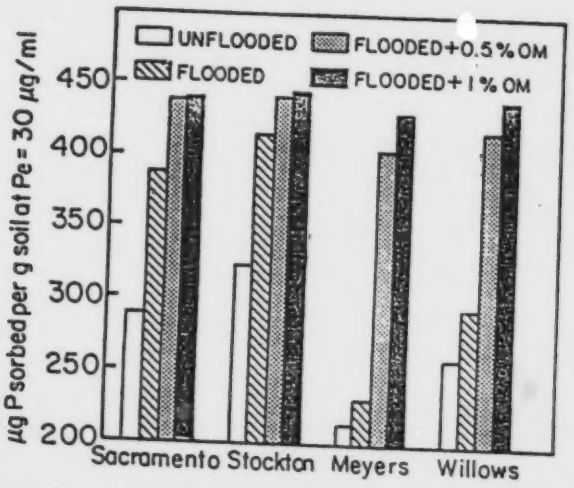


Figure 2. Effects of anaerobic decomposition of organic matter on P sorption. Incubation time was 4 d at 20°C. (Reproduced from Sah and Mikkelsen (1986).)

ammonia, together with phenols and carbohydrates in the nest soils of harvester ants (*Messor* ebeninus) in Gilat (Israel). They also studied the nutrient status of these soils. According to Ofer et al. (1982), FAs and HAs are formed probably due to the mixing activity of the Harvester ants which enhanced the microbiological processes leading to formation of HSs. In addition, the higher concentration of HSs in the soil of ants' nests as compared to field soil and nitrates was in good correlation with the increase of biomass growing on ants' mounds (Ofer et al. 1982). Furthermore, in the context of dynamics of OM in soils, studies on the addition of ^{14}C-labelled glucose, cellulose, and proteins from algae and of labelled polysaccharides from wheat straw indicated that allophanic soils (mineral ones) caused a major reduction in the degradation rate of added carbonaceous materials compared to non-allophanic soils (ref. cited in Paul (1984)).

C. SOIL AGGREGATE STABILITY

In 1974, Dhoot and associates investigated the role played by polysaccharides in soil aggregation under aerobic and anaerobic conditions. The Ludhiana (India) sandy loam soil samples mixed with various polysaccharides, viz., starch, cellulose, guar gum, acacia gum, pectin, and glucose were incubated for 75 days. (Figure 3). It is evident from Figure 3(A) that glucose, guar gum, and pectin enhanced aggregation during the earlier period of incubation, but that their effect gradually declined. According to Dhoot et al. (1974), probably easily decomposable polysaccharides did not persist

long in the soil and the cementing agents produced during decomposition were also metabolized at later stages of incubation. Starch and cellulose yielded aggregation after 15 days of incubation but their influence continued to increase up to 75 days (see Figure 3(A)). It is noteworthy that starch which could be decomposed faster by microorganisms, behaved like cellulose. All the investigated polysaccharides were less effective under anaerobic conditions (Figure 3(B)). Reduced aggregation under saturated soil conditions may be due to change in the nature of the cementing agents produced (Dhoot et al. 1974). It is interesting to mention that starch amended soil when autoclaved gave large size aggregates (Dhoot et al. 1974). Recently, Chaney and Swift (1986) also concluded that the soil aggregate stability induced by glucose was of transient nature and declined over a period of 12 weeks.

Bathke and Blake (1984) conducted investigations to determine the differences in mean weight diameter (MWD) of soil aggregates and wet aggregate stability as affected by corn and soyabean crops along with their residue. The results of the crop residue studies are documented in Table 2. This table reveals that in the spring of 1981, soil aggregates were smaller following soyabeans than corn when residue remained in place (not switched) during winter. MWDs were smaller when corn residue was removed from the corn plot than the case when it remained (see Table 2). There was no consistent effect of the treatments on aggregate stability in the spring of 1981 (Table 2).

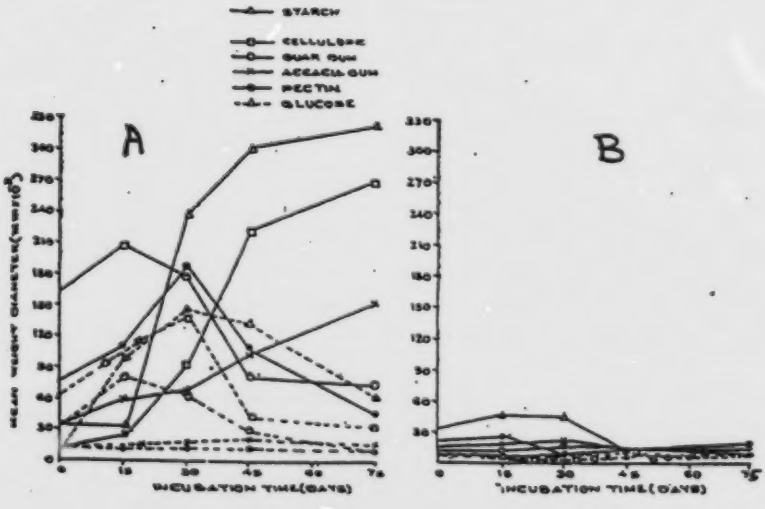


Figure 3. Effect of different polysaccharides on sandy loam aggregation under aerobic (A) and anaerobic (B) conditions. (Reproduced from Dhoot et al. (1974).)

The relative role of the carboxyl and phenolic hydroxy groups of HAs in the generation of water-stable soil aggregates has been investigated by Chakraborty et al. (1982). The dialysed humic acid solutions were fractionated to different molecular weights (< 4,000; 4,000-10,000; 10,000-50,000 and > 50,000) by column chromatography utilizing Sephadex gels G25, G50, and G75. All the fractions up to molecular weight 50,000 were combined and thus two fractions were achieved (< 50,000 and > 50,000). The results of the relationship of the soil aggregate size with the contents of the acidic functional groups of these two fractions of HAs are recorded in Table 3. This table shows that, in the case of HAs of molecular weights < 50,000 with increase in size of the aggregates, total together with carboxyl acidities increased in a regular manner; thereby indicating that carboxyl groups were mainly responsible for stabilizing soil aggregates (Chakraborty et al. 1982). On the other hand, in the case of HAs of molecular weight greater than 50,000, the total and carboxyl acidities decreased with aggregate size but there was a mixed trend in the content of the acidic hydroxy groups (Table 3) revealing that phenolic OH groups of high molecular weight HAs are operative in stabilizing soil aggregates (Chakraborty et al. 1982). Results of similar studies were also published by Chakraborty and associates in 1979. Similar results were presented by Goh and Huang (1986) who postulated that the interaction between carboxylic and phenolic groups of tannic acid with Al to form hydroxy-Al-tannate complexes, facilitated the formation of linkages among the planar and edge surfaces of montmorillonite, thus promoting aggregation of the clay particles.

Table 2. Aggregate mean weight diameter (MWD) and stability as affected by residue management (spring, 1981). (Reproduced from Bathke and Blake (1984).)

Property	Corn, corn residue	Corn, no residue	Soybeans, corn residue	Soybeans, soybean residue
		Lamberton		
MWD, mm	2.20 a*	2.09 b	1.95 c	1.89 c
Aggregate stability %	38.6 a	31.9 b	29.5 bc	26.6 c
		Rosemount		
MWD, mm	1.98 a	1.80 b	1.73 bc	1.61 c
Aggregate stability %	26.0 a	28.9 a	30.3 a	28.6 a
		Waseca		
MWD, mm	1.61 a	1.38 bc	1.46 ab	1.22 c
Aggregate stability %	40.2 a	38.4 a	36.6 a	41.1 a

*Values in a row followed by same letter are not significantly different according to Duncan's Multiple Range Test, $\alpha = 0.05$.

It is interesting to mention that Giovannini and Sequi (1976) reported the extraction of iron (Fe), aluminum (Al) and OM by acetylacetone in benzene or in water (Table 4). Table 4 shows that similar amounts of iron and aluminum were extracted by acetylacetone in either benzene or water, but OM was extracted in detectable amounts only by acetylacetone in water. Giovannini and Sequi (1976), stated that the Al and Fe extracted by chelating acetylacetone solution was possibly predominantly linked to the OM in the soil. The Reactions (1) and (2) show two stages of extractions seen in Table 4 (Giovannini and Sequi 1976):

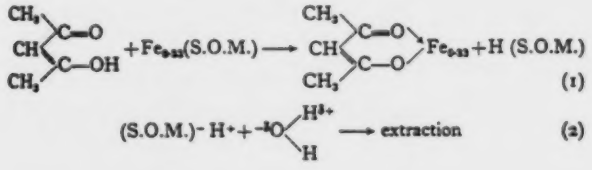


Table 3. Total, carboxyl and phenolic hydroxyl acidities (m.e./g) of different molecular ranges. (Reproduced from Chakraborty et al. (1982)).

Aggregate size (mm)	Molecular weight range							
	<50,000				>50,000			
	Total	COOH	OH	OH : COOH	Total	COOH	OH	OH : COOH
				Chinsurah (India)				
Whole soil	6.95	4.65	2.30	0.494	4.55	2.00	2.55	1.275
0.20	7.75	5.25	2.50	0.476	4.85	1.50	3.35	2.233
0.25	7.60	5.30	2.30	0.434	4.85	1.40	3.45	2.464
0.50	7.95	5.75	2.20	0.382	4.35	1.35	3.00	2.222
1.00	8.25	6.20	2.05	0.330	4.30	1.30	3.00	2.308
2.00	8.50	6.50	2.00	0.307	4.00	1.20	2.80	2.333
				Jhargram (India)				
Whole soil	5.95	3.60	2.35	0.653	3.25	1.35	1.90	1.407
0.25	6.25	4.00	2.25	0.562	3.35	1.20	2.15	1.791
0.50	6.50	4.15	2.35	0.566	3.15	1.05	2.10	2.000
1.00	6.85	4.45	2.20	0.494	2.90	0.95	1.95	2.052
2.00	7.35	5.10	2.25	0.441	2.85	0.90	1.95	2.166
				Bishnupur (India)				
Whole soil	4.95	3.25	1.70	0.538	1.05	0.50	0.55	1.100
0.20	5.15	3.20	1.95	0.609	3.70	1.40	2.30	1.643
0.25	5.25	3.10	2.15	0.693	3.65	1.30	2.35	1.807
0.50	5.65	3.65	2.00	0.548	3.10	1.05	2.05	1.952
1.00	5.85	3.95	1.90	0.481	2.00	0.90	1.10	1.222
2.00	6.10	4.50	1.65	0.366	2.20	0.70	1.50	2.143

Table 4. Extraction of iron, aluminuium, and organic matter (OM) by acetylacetone in benzene or in aqueous solution, as percent of total content.

Soil	(symbol)	Acetylacetone in benzene			Acetylacetone in water		
		Fe	Al	O.M.	Fe	Al	O.M.
Terra Rossa	(TR)	0.56	0.57	<0.5	0.61	0.57	11.3
Clay Alluvial	(CA)	0.39	0.26	<0.5	0.43	0.28	19.8
Podzol A_1 horizon	(A_1)	7.50	1.39	<0.5	7.75	1.41	7.8
Podzol B_h horizon	(B_h)	22.22	4.66	<0.5	22.77	4.92	49.2
Pisa Reclaimed Peaty soil	(P_s)	16.20	5.93	<0.5	15.94	6.11	6.9

Moreover, Chaney and Swift (1986) noticed that on adsorbing HAs onto the calcium saturated soil minerals and then incubating for 14 days, significant increases in aggregate stability resulted which persisted with time. The stability of the re-formed aggregates was even greater when the samples were incubated with salts of HAs plus 0.5% glucose. It should be mentioned that the calcium saturated soil without HAs amendment gave very little aggregate stability with or without glucose addition (Chaney and Swift 1986). Likewise, Na-salt of HAs provided about 3 times greater aggregate stability than Ca-salt of these macromolecules. These authors suggested that HSs are particularly involved in the formation of micro-aggregates.

D. SOIL EROSION

In the context of water erosion of soils, Don and coworkers (1983) examined the relationship between clay dispersibility ratio and organic carbon content (x) of six surface soils, two subsurface soils and one organic soil from the Menomonee River Watershed, Wisconsin (U.S.A.). Simple correlation coefficients relating clay dispersibility ratios of the six surface soils and x values are recorded in Table 5. It is evident from this table that the clay dispersibility ratio was significantly correlated with organic carbon content in an inverse relationship. It is worth mentioning that the clay fractions of soils fertilized with urea and calcium nitrate were less dispersible than in the case of the control (Goh et al. 1987).

Voroney et al. (1981) compared the amounts of OM in native prairie and in an adjacent cultivated field with the output from a simulation model describing OM dynamics. The effects of past and possible future soil management practices and the loss of organic carbon through rainfall erosion were incorporated into the simulation study. Figure 4 indicates that soil erosion had a drastic effect on organic carbon levels especially after 50-80 years of cultivation, resulting in a continual decline of OM content. Moreover, doubling the organic C content of eroded sediments resulted in a much faster rate of organic C depletion (see Figure 4). Also, simulation showed that the

Table 5. Correlation coefficients for linear, inverse, and logarithmic relationships between clay dispersibility ratio[a] and soil organic C (x). (Reproduced from Dong et al. (1983).)

Time of shaking[b]	Six surface soils[c]			Six surface soils and two subsoils[c]			Six surface soils and two subsoils and one organic soil[c]		
h	x	$1/x$	$\log_{10}x$	x	$1/x$	$\log_{10}x$	x	$1/x$	$\log_{10}x$
0.5	−0.762	0.790	−0.797	−0.804*	0.981**	−0.940**	NA	NA	NA
1	−0.775	0.928**	−0.874*	−0.822*	0.987**	−0.959**	NA	NA	NA
4	−0.935**	0.904*	−0.951**	−0.859**	0.985**	−0.932**	−0.612	0.968**	−0.930**
16	−0.883*	0.853*	−0.898*	−0.789*	0.989**	−0.932**	−0.547	0.980**	−0.879**
32	−0.763	0.642	−0.730	−0.740*	0.976**	−0.902**	−0.569	0.967**	−0.879**
64	−0.580	0.492	−0.553	−0.736*	0.963**	−0.892**	−0.555	0.953**	−0.867**

[a]Clay dispersibility ratio = clay-size fraction obtained by shaking in water/clay-sized fraction obtained by ultrasound.
[b]Shaking treatment consisted of end-over-end agitation of a 1:10 (wt:vol) soil-water mixture.
[c]*, significant at P = 0.05, and **, significant at P = 0.01; NA, no data available.

rate of depletion of soil organic carbon can be drastically reduced by continuous cropping and by returning crop residues to the soil to reduce soil erosion (Figure 4).

The distribution of OM as a function of particle size in the wind-blown soil aerosol yielded during spring dust storms in western Texas (U.S.A.) has been reported by Zenchelsky and coworkers (1976). Table 6 records the mass-ratio of total organic carbon (TOC) to total particulate for each size range measured at three wind velocities, viz., 7.3, 9.3, and 11.4 m/sec. It is clear from this table that the mass distribution of TOC decreases as the particle size increases at all three of the wind velocities. In addition, TOC content in each size fraction decreases with the rise in wind velocity although the corresponding particulate concentration increases. Furthermore, wind erosion influences on soil texture and SOM has been also reported by Lyles and Tatarko (1986).

It is interesting to mention that Isbister and associates (1980) quantitatively measured microbial cellulose degradation by monitoring metabolically evolved $^{14}CO_2$ following addition of ^{14}C-labelled cellulose or starch to the soil sample. The results concerning the inhibition effects of various levels of phenol on the microbial degradation of cellulose in soil are given in Table 7. It is apparent from this table that, as the levels of phenol increased, the rate of degradation of cellulose decreased.

Finally, in laboratory experiments, Wood and Oster (1985) evaluated the effects of celluose xanthate and polyvinyl alcohol (PVA) on water infiltration, erosion, and crusting of soils at exchangeable sodium fraction (E_{Na}) of 0, 0.05, and 0.10. In eight of the nine cases of untreated soils, erosion was 40 to 70% higher during saline irrigation than during nonsaline irrigation. According to Wood and Oster (1985), this observation is attributable to the dislodging of

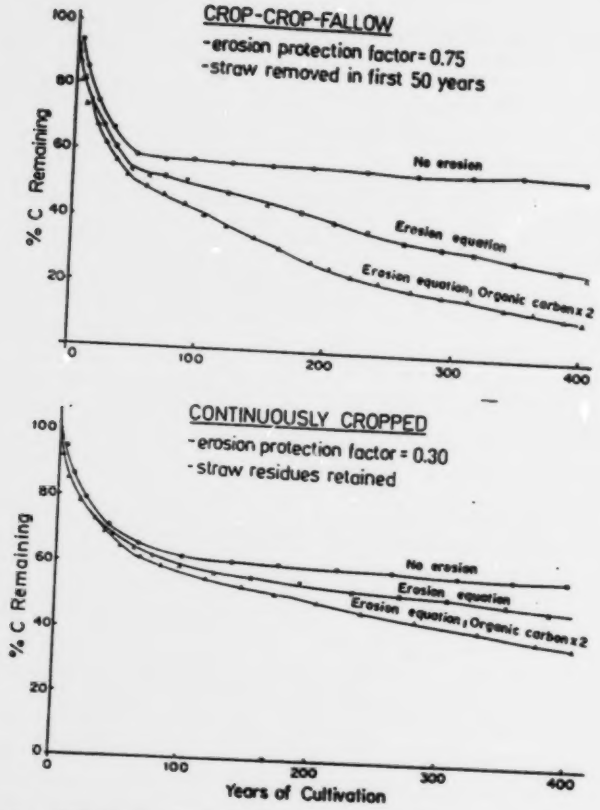


Figure 4. Effect of rainfall-induced soil erosion, calculated by the universal soil loss equation, on the organic C remaining in the surface 15 cm of a cultivated Oxbow soil. (Reproduced from Voroney et al. (1981).)

large particles during irrigation of the freshly prepared surface. In addition PVA and xanthate treatments nearly eliminated erosion on all studied soils in the case of both saline and nonsaline irrigation, regardless of E_{Na} levels (Wood and Oster 1985).

E. PESTICIDES

The results for the sorption of atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) onto the surfaces of a large number of soils with widely variable organic carbon contents (0.1 to 27.1%) are presented in graphical form in Figure 5 (references cited in Stevenson (1972).)

Table 6. Mass ratio of TOC to particulate in each particle size range at three wind velocities. (Reproduced from Zenchelsky et al. (1976).)

Particle radii, μm	Mass ratio of TOC to particulate, %*		
	7.3 $msec^{-1}$	9.3 $msec^{-1}$	11.4 $msec^{-1}$
0.21-0.42	18.1 ± 0.5	(25.2)	3.0 ± 0.2
0.42-0.85	4.5 ± 0.6	(5.9)	1.6 ± 0.3
0.85-1.6	1.7 ± 0.6	(1.4)	0.8 ± 0.03
1.6 -3.4	0.7 ± 0.1	(0.3)	0.4 ± 0.02
>3.4	0.7 ± 0.2	(0.2)	0.02± 0.002

*The ± values are mean deviations of duplicate samples that were obtained in separate, successive collections within a short time period. The data within parentheses are from single determinations with a sampling time that resulted in visible overloading of the collector.

Table 7. Inhibition* of ^{14}C-cellulose (10 μCi/ml) degradation by phenol. (Reproduced from Isbister et al. (1980).)

ppm Phenol	% Inhibition of cellulose degradation at 17 hours	% Inhibition of cellulose degradation at 200 hours
500	72.5	44.0
1000	97.6	56.5
1500	98.4	60.3
2000	98.6	89.1
5000	98.7	99.5

*Percent inhibition of cellulose degradation by phenol was calculated by comparison of detected cpm from untreated soil and detected cpm from phenol treated soils.

It can be seen from Figure 5 that up to 8% OM content, both mineral and organic surfaces contributed to sorption; at higher OM levels sorption occurred almost exclusively on organic surfaces.

The influence of rice straw on parathion (structure is shown below) degradation in uninoculated flooded alluvial soil is described in Table 8 (Sethunathan 1973). In uninoculated soils, rice straw enhanced the degradation of parathion via nitro reduction (see Table 8). On the other hand, in soils inoculated with an enrichment culture which showed an exceptionally high ability to hydrolyze parathion, rice straw amendments inhibited parathion hydrolysis to p-nitrophenol and diethyl thiophosphoric acid (Sethunathan 1973).

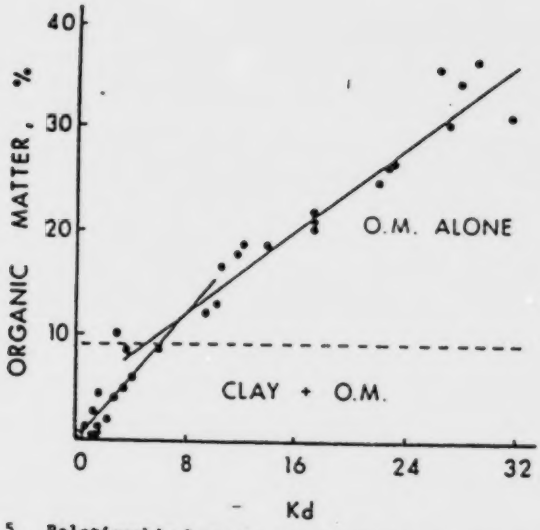
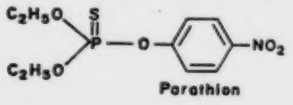


Figure 5. Relationship between organic matter content and the amount of atrazine adsorbed by 36 soils. Kd = μmoles adsorbed per g/μmoles per ml equilibrium solution. (Reproduced from Stevenson (1972).)

Table 8. Effect of added rice straw on parathion degradation in uninoculated soil (reproduced from Sethunathan (1973).)

Days after parathion addition	μg Parathion/20 g soil recovered			
	0	3	10	20
Rice straw (‰ w/w)				
0	465	384	364	221
0·5	392	360	53	0
1	483	284	0	0
2	451	237	0	0



Parathion

The data collected by the studies of the effects of the herbicide metoxuron (N-(3-chloro-4-methoxy)N,N-dimethylurea) on the OM degradation consequences on soil aggregate stability is plotted in Figure 6 (Sylvestre 1978). This figure provides evidence that soil aggregate stability imparted by 1% cellulose powder is suppressed much on increasing rate of application of the herbicide by 10-fold (compare Figure 6(2) with 6(1)). However, such suppressing effect of the herbicide on the soil aggregate stability could be avoided when 1% alfalfa hay was used instead of 1% cellulose powder (see Figure 6(2) and 6(3)).

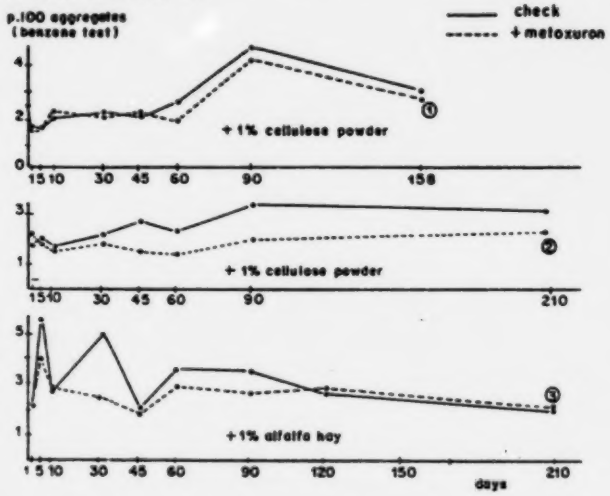


Figure 6. Influence of metoxuron on the rate of the stable aggregates after an organic matter supply.
① : + metoxuron (normal rate x 20)
② and ③: + metoxuron (normal rate x 200).
(Reproduced from Sylvestre (1978).)

Further literature concerning the interactions of pesticides with both soil humic substance and soil non-humic substances has been described by Choudhry (1982, 1984), Stevenson (1982), and Schnitzer and Khan (1972).

F. CONCLUDING REMARKS

With the exception of two articles by Chakraborty et al. (1982, 1979), no other research paper included any information on the structural aspects of soil organic matter (SOM) and SOM chemistry and their role in sustained agricultural yields via enhancement of soil fertility, enhancement of soil aggregate stability, reduction of soil erosion and the effects of pesticides. All such researchers interpreted their experimental data in this important field of soil science utilizing the values of total organic carbon (TOC) only. There is no doubt that soil samples having the same TOC levels may contain SOM of different chemical structures and of different

chemistry. Therefore, it is extremely important to initiate research to expand our fundamental knowledge of SOM in the context of chemistry in relation to:

- sustained agricultural production,
- soil fertility,
- soil aggregate stability,
- soil erosion,
- organic mineral complexes, and
- pesticides.

G. REFERENCES

Bathke, G.R. and G.R. Blake, Soil Sci. Soc. Am. J. 48, 1398-1401 (1984).

Chaney, K. and R.S. Swift, J. Soil Sci. 37, 329-335 (1986).

Chaney, K. and R.S. Swift, J. Soil Sci. 37, 337-343 (1986).

Chakraborty, G., S.K. Banerjee, and S.K. Gupta, J. Indian Soc. Soil Sci. 27, 129-132 (1979).

Chakraborty, G., S.K. Banerjee, and S.K. Gupta, J. Indian Soc. Soil Sci. 30, 378-380 (1982).

Choudhry, G.G., "Humic Substances: Structural, Photophysical, Photochemical and Free Radical Aspects and Interactions with Environmental Chemicals". Gordon and Breach Sci. Publ., New York, pp.1-185 (1984).

Choudhry, G.G., "Interactions of Humic Substances with with Environmental Chemicals". The Handbook of Environmental Chemistry, Vol 2/Part B, Ed. O. Hutzinger. Springer-Verlage, New York, pp.103-128 (1982).

Dhoot, J.S., N.T. Singh, and S.S. Brar, J. Indian Soc. Soil Sci. 22, 217-219 (1974).

Dong, A., G. Chesters, and G.V. Simsiman, Soil Sci. 136, 208-212 (1983).

Foster, H.L., Trop. Agric. (Trinidad) 57, 123-132 (1980).

Giovannini, G. and P. Sequi, J. Soil Sci. 27, 140-147 (1975).

Goh, T.B. and P.M. Huang, Clays Clay Miner. 34, 33-44 (1986).

Goh, T.B., M.J. Dudas, S. Pawluk, and J.T. Harapiak, Geoderma 40, 177-192 (1987).

Ibister, J.D., R.S. Shippen, and J. Caplen, Bull. Environ. Contam. Toxicol. 24, 570-574 (1980).

Lyles, L. and J. Tatarko, J. Soil and Water Conservation, 191-193 (1986).

Ofer, J., R. Ikan, and O. Haber, Commun. in Soil SCi. Plant Anal. 13, 737-747 (1982).

Paul, E.A., Plant and Soil 76, 275-285 (1984).

Sah, R.N. and D.S. Mikkelsen, Soil Sci. 142, 267-274 (1986).

Schnitzer, M. and S.U. Khan, "Humic Substances in the Environment". Marcel Dekker Inc., New York, pp.1-304 (1972).

Schnurer, J., M. Clarholm, and T. Rosswall, Soil Biol. Biochem. 17, 611-618 (1985).

Sethunathan, N., Soil Biol. Biochem. 5, 641-644 (1973).

Stevenson, F.J., "Humus Chemistry: Genesis, Composition, Reactions". John Wiley & Sons, New York, pp.1-432 (1982).

Stevenson, F.J., J. Environ. Quality 1, 333-343 (1972).

Sylvestre, G.S.-, Chemosphere 7, 821-826 (1978).

Voroney, R.P., J.A. van Veen, and E.A. Paul, Can. J. Soil Sci. 61, 211-224 (1981).

Wood, J.D. and J.D. Oster, Soil Sci. 139, 243-249 (1985).

Zenchelsky, S.T., A.C. Delany, and R.A. Pickett, II, Soil Sci. 122, 129-132 (1976).

SOME EFFECTS OF MOISTURE STRESS ON LENTIL

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ABSTRACT

Response of lentil (Lens culinaris Medik.) to moisture stress imposed at three different stages of growth was examined in a growth chamber experiment. Early, prolonged stress reduced the time required to produce mature seed. Plants stressed at later growth stages did not possess this developmental plasticity. Rewatering of stressed plants encouraged new vegetative and reproductive growth, effectively extending the flowering stage. Moisture stress also resulted in differences in phenological development. Mechanisms of drought tolerance and avoidance were dependent on the stage of growth at which stress was imposed. In early stressed plants (pre-bud) paraheliotropism, reduced leaflet size and limited production of flowers were observed. Where stress was imposed at first flower and early pod development, extensive leaf loss and abortion of floral structures resulted in reduced dry matter and seed yields.

Introduction

Lentil (Lens culinaris Medik. 'Eston') is a high protein crop used primarily for human consumption. Introduced into western Canada in the early 1970s, conclusive information regarding the production of lentil is limited and, of that available, little is applicable to the western Canadian agroclimate.

Lentil has an indeterminate growth habit and it has been suggested that some stress, such as a drought stress, is required during flowering to stimulate heavy pod set (Saskatchewan Agriculture 1985). However, studies conducted to examine the effect of drought on the yield of various legumes which, like lentil, exhibit strong ontogenetic indeterminance, generally do not support this contention. Hiler et al. (1972), in their studies with southern peas (Vigna sinensis L.), reported that the flowering period was the most sensitive stage to plant water deficits although plant growth and seed yield were reduced by water deficits at all stages of growth. Similarly, Turk et al. (1980) found that drought at flowering and pod fill growth stages of cowpea (Vigna unguiculata L.) had significant adverse effects on seed yield. However, in a subsequent paper, Turk and Hall (1980) suggested that, in environments where suppression of vining is beneficial, moderate drought stress during the vegetative stage may be necessary for the achievement of maximum seed yield of cowpea. In contrast, Summerfield et al. (1976) reported that seed yield of cowpea was reduced by repeated wilting prior to flowering whereas wilting after flowering did not reduce yield.

The objective of this study was to examine the response of lentil to moisture stress imposed during different stages of growth.

Materials and Methods

A completely randomized experiment consisting of 4 treatments and 3 replicates was conducted in a growth chamber to investigate the effect of moisture stress, applied at different physiological stages, on growth and yield of lentil.

The soil used was obtained from the surface 15 cm of a St. Claude loamy fine sand (Ehrlich et al. 1957), which is classified as a Rego Black Chernozem, carbonated phase, in the Canadian System of Soil Classification. The soil had a pH of 7.2 (1:3 soil-water paste) and a conductivity of 0.3 dS m^{-1}. Field capacity was 24% by volume. Permanent wilting point was 7.3%, as determined using a pressure membrane apparatus and calculated using the equation proposed by Shaykewich (1965). Prior to potting, the previously air dried soil was treated with 30 ug g^{-1} N as reagent grade urea, 100 ug g^{-1} P as KH_2PO_4 , 200 ug g^{-1} K as KH_2PO_4 and K_2SO_4, 10 ug g^{-1} Zn as $ZnSO_4.5H_2O$ and 37 ug g^{-1} S from the latter three sources. The fertilizers were dissolved in deionized water, sprayed onto and thoroughly mixed with six kg of soil. Following nutrient addition, the soil was placed into pots lined with polyethylene bags.

Ten lentil (Lens culinaris Medik. 'Eston') seeds, inoculated with Nitragin Corporation 'C'culture (Rhizobium leguminosarum) were sown 2.5 cm deep in each pot. The pots were then brought up to 2/3 field capacity by weight through the addition of deionized water. Following germination and emergence, lentils were thinned to four plants per pot, and pots were brought up to field capacity through the addition of deionized water.

The experiment was conducted in a growth chamber in which there was a 16 hr daylength and 8 hr night photoperiod regime. The light source was Sylvania cool white supplemented with 10% incandescent light. The photosynthetically active radiation was 550 uE m^{-2} sec^{-1} at plant canopy height. Day/night temperatures were maintained at 22C and 15C, respectively. Relative humidity was maintained at 50% during the day and 80% during the night.

Pots were weighed on a daily basis and the soil was restored to field capacity through the addition of deionized water as required. For the control treatment (treatment 1), which was intended to simulate stress-free conditions, field capacity was maintained until harvest. During growth stages in which heavy water use was noted, maintenance of field capacity was achieved by adding water twice daily or as required. Moisture stress, applied to treatments 2,3 and 4 at pre-bud, first flower and early pod fill stages of growth, respectively, was simulated by withdrawing the daily additions of water at the appropriate growth stages. Water was withheld until the plants had begun to visibly wilt. The onset of wilting was determined subjectively and each pot was considered individually. When wilting was noted, field capacity was restored. Rewatering restored turgidity and no plants were allowed to permanently wilt. Having restored the soil to field capacity, water was again withheld and the plants allowed to wilt. This repetitive pattern of wilting and watering was maintained until harvest.

Due to the indeterminate growth habit of lentil and complex flowering responses to drought, growth stages are somewhat ambiguous and

difficult to define. For the purposes of this experiment 'first flower' was defined as the stage at which 50% of the plants had open flowers and 'maturity' was defined as the stage at which some mature seed was present in early pods. 'Crop duration' denotes days from seeding to time at which rewatering of plants did not encourage vegetative regrowth or stimulate flowering.

Plants were harvested 95 days after seeding. The aerial portion of the plants were harvested and mixed with any senescent material collected prior to harvest. Plants were separated by hand into seed and straw components, oven dried and then finely ground. Nitrogen content of the plant material was determined by a modified Kjeldahl-Gunning method as described by Bremner (1965). Nitrogen in the plant material is reported on an oven dry basis. Protein concentration was determined using 6.25 as the factor for crude protein.

Results and Discussion

Stress treatments were initiated at 29, 47, and 56 days after seeding corresponding to pre-bud, first flower and early pod development, respectively. Lentil plants stressed at first flower and early pod development wilted within two to four days of watering to field capacity. In contrast, lentil plants stressed at the pre-bud stage tended to use water conservatively, maintaining turgor for up to six days after watering, suggesting that these plants had developed some moisture stress avoidance mechanisms.

Early stress did not affect the time of flowering and all plants reached first flower 47 days after seeding. Similar results were reported by Lawn (1982b) who found that the effects of stress on the time of flowering of cowpea were small. Although time to first flower was unaffected by stress, lentil exhibited some developmental plasticity through faster development from flowering to maturity in early drought stressed plants. Plants stressed at the pre-bud stage produced mature seed 77 days after seeding whereas the control and later stressed treatments reached maturity at approximately 86 days. Other researchers (Turk et al. 1980; Lawn 1982a,b) obtained similar results, observing that cowpea exhibits some tendency to escape drought through faster development in response to stress. Crop duration was also affected by drought stress. Rewatering of moisture stressed plants stimulated rapid vegetative growth and a new flush of flowers for all moisture stress treatments. This resurgence of growth effectively extended the flowering stage despite the presence of mature seed. Crop duration of unstressed plants was 86 days as opposed to 96 days for the stressed plants. Similarly, Lawn (1982a) reported that new flushes of vegetative growth and flower buds were stimulated by irrigation of cowpea in the mid-podfilling stage, effectively extending crop duration.

In addition to differences in maturity and crop duration, differences in phenological development resulted from the imposition of moisture stress. Lentil plants which were allowed to repeatedly wilt from the pre-bud stage exhibited a strong paraheliotropic response, e.g., orientation of the leaflets parallel to incoming radiation (Ehleringer and Forseth 1980). As a consequence of paraheliotropism, absorption of incoming radiation is minimized (Ehleringer and Forseth 1980), effectively reducing the heat load on the leaf, leaf temperature and

transpiration rate (Forseth and Ehleringer 1980; Lawn 1982a). Ehleringer and Forseth (1980) have suggested that paraheliotropism should be of tremendous adaptive value in allowing plants to survive drought stress. Lentil plants stressed at later growth stages (treatments 3 and 4) did not share the paraheliotropic response.

In addition to paraheliotropism, lentil plants subjected to early and prolonged drought stress (treatment 2) developed smaller leaves than later stressed or unstressed lentil plants. Generally a reduction in leaf area is associated with water deficits (Kramer 1963). Wilting during bloom and early podfill did not result in a reduction in leaf size as vegetative development was essentially completed at the time of stress. However, extensive leaf loss occurred for both treatments shortly after the water was withheld. Thus at later growth stages plants responded to moisture stress by reducing leaf area through leaflet abscission.

Water stress resulted in a significant reduction in dry matter yields, regardless of the developmental stage at which stress was applied (Table 1). The lowest yield was obtained where lentil plants were stressed for the longest duration, namely from the pre-bud growth stage. This yield reduction was attributed to both reduced leaf and total plant size. An attempt was made to collect any senescent leaves and thus reductions in dry matter did not simply reflect loss of leaf dry matter. Lentil plants which were stressed at first flower and early pod development had, to a large degree, completed vegetative growth at the time of stress and thus significant reductions in total dry matter were primarily due to reduced seed yields.

Seed yields were significantly reduced by moisture stress, although no significant differences existed among the three moisture stress treatments (Table 1). Several possible mechanisms by which seed yields were reduced may have occurred. Extensive leaf loss associated with moisture stress applied at first flower and early pod development may have decreased the nitrogen available for translocation out of the leaves to the reproductive structures and thus may have limited seed development. Moisture stress applied at first flower also resulted in the abortion of floral structures, thereby limiting pod formation. When stress was applied during the pre-bud stage, production of floral structures was restricted, fewer flowers wilted and abortion of floral structures did not occur, suggesting that the early stressed lentil plants had developed a moisture stress avoidance mechanism by which flowering was restrained, thereby minimizing the demand on the limited moisture supply. Thus, several mechanisms including restricted number of flowers, abortion of floral structures, and limited seed development may all have contributed to reduced seed yields. Furthermore, the extent to which each mechanism contributed to the reduction in seed yields may have varied, depending on the developmental stage at which stress was applied.

Nitrogen accumulation in the seed was also significantly affected by moisture stress (Table 1). Moisture stress applied at pre-bud, first flower and early pod development reduced seed N, primarily as a function of reduced seed yield. Thus, protein concentration in the seed was not significantly affected by moisture stress (Table 1).

Harvest index, given by the ratio of seed dry matter to total dry

matter, was not significantly affected by moisture stress treatments (Table 1). However, the data suggest that moisture stress served to limit seed production to a greater extent than vegetative production. In conclusion, data indicate that under controlled conditions, moisture stress leads to a reduction in dry matter and seed yield of lentil and does not, as has been suggested, stimulate heavy pod set. However, these results do not necessarily reflect the response of lentil to drought under field conditions and it is suggested that further research is required.

ACKNOWLEDGEMENTS

The authors are pleased to acknowledge the financial support provided to this study by the Natural Sciences and Engineering Research Council of Canada.

References

Bremner, J.M. 1965. Total nitrogen. Pages 1164-1166 in C.A. Black, ed. Methods of soil analysis. Part II. Chemical and microbiological properties. Agronomy 9. Am. Soc. Agron., Madison, Wis.

Ehleringer, J. and Forseth, I. 1980. Solar tracking by plants. Science 210: 1094-1098.

Ehrlich, W.A., Poyser, E.A. and Pratt, L.E. 1957. Report of reconnaisance soil survey of Carberry map sheet area. Manitoba Soil Survey Rep. No. 7. Manitoba Department of Agriculture.

Forseth, I. and Ehleringer, J. 1980. Solar tracking response to drought in a desert annual. Oecologia 44: 159-163.

Hiler, E.A., van Banvel, C.H.M., Hossain, M.M. and Jordan, W.R. 1972. Sensitivity of southern peas to plant water deficit at three growth stages. Agron. J. 64: 60-64.

Kramer, P.J. 1963. Water stress and plant growth. Agron. J. 55: 31-35.

Lawn, R.J. 1982a. Response of four grain legumes to water stress in south-eastern Queensland. I. Physiological response mechanisms. Aust. J. Agric. Res. 33: 481-496.

Lawn, R.J. 1982b. Response of four grain legumes to water stress in south-eastern Queensland. II. Plant growth and soil water extraction patterns. Aust. J. Agric. Res. 33: 497-509.

Saskatchewan Agriculture. 1985. Varieties of grain crops for Saskatchewan. Prepared by: The Grain Crops Committee of The Saskatchewan Advisory Council on Crops.

Shaykewich, C.F. 1965. The relationship between soil components and soil physical constants of some Manitoba soils. M.Sc. Thesis, University of Manitoba. Winnipeg, Manitoba.

Summerfield, R.J., Huxley, P.A., Dart, P.J. and Hughes, A.P. 1976. Some effects of environmental stress on seed yield of cowpea (Vigna unguiculata (L.) Walp.)cv. Prima. Plant Soil 44: 527-546.

Turk, K.J., A.E. Hall and C.W. Asbell. 1980. Drought adaptation of cowpea. I. Influence of drought on seed yield. Agron. J. 72: 413-420.

Turk, K.J. and A.E. Hall. 1980. Drought adaptation of cowpea. III. Influence of Drought on plant growth and relations with seed yield. Agron. J. 72:428-433.

Table 1. Response of lentil to moisture stress imposed at different growth stages.

Moisture stress treatment	Dry matter g pot^{-1}	Seed g pot^{-1}	Seed N mg pot^{-1}	Seed protein g kg^{-1}	Harvest index %
No stress	61.8 a*	27.4 a	1046 a	238	44.4
Stress from pre-bud	36.2 c	15.2 b	559 b	230	41.8
Stress from first flower	41.5 b	14.0 b	507 b	228	33.8
Stress from early pod	40.2 bc	15.5 b	573 b	231	38.5
Coefficient of variation	5.1	9.0	9.0		
Standard deviation	2.3	1.6	60.5		

*Means in each column followed by the same letter do not differ significantly at P = 0.05 (Duncan's New Multiple Range Test).

REACTIONS OF TRIVALENT AND HEXAVALENT FORMS OF CHROMIUM WITH SOIL MINERALS

M.M. Cheslock and Tee Boon Goh

ABSTRACT

Chromium in soils exists in two common oxidation states, that is, trivalent (or Cr(III)) and hexavalent (or Cr(VI)) chromium. Cr(III) is essential to both human and animal nutrition and may be of benefit to plant growth in trace amounts. Cr(VI) is known to be toxic at low concentrations to both plants and animals.

The purpose of the investigation was to study the adsorption and subsequent release of chromium by the soil oxides, haematite and birnesite and the clay minerals, montmorillonite and vermiculite in order to assess the potential availability of chromium to plants. Solutions of Cr(III) or Cr(VI) were equilibrated at pH 4 or 5 with the soil minerals and the amounts adsorbed measured. The strength of adsorption was assessed by extracting the adsorbed chromium using 0.1 M KH_2PO_4 followed by 0.5 M $CaCl_2$ solutions. Analyses of the potential toxicity is expressed as the amount of Cr(III) that was oxidized to Cr(VI) during the adsorption by soil minerals.

The results showed that the adsorption capacities of the oxides for both forms of chromium exceeded those of the clay minerals. Cr(III) was tightly bound to oxides but not the clay minerals. In contrast, Cr(VI) was very easily released from haematite and birnesite but was extracted with difficulty from montmorillonite. Some of the Cr(III) adsorbed by birnesite was oxidized to Cr(VI). The large differences in the amounts of Cr(III) and Cr(VI) adsorbed by common soil minerals are likely the result of different bonding mechanisms.

INTRODUCTION

In soils, chromium occurs in one of four states, depending on the values of pH and Eh which exist: there are two trivalent forms, the Cr^{+3} cation and the CrO^{2-} anion, and there are two hexavalent anion forms, $Cr_2O_7^{-2}$ and CrO_4^{-2} (Bartlett and Kimble, 1976a). The trivalent forms of chromium are considered as stable and relatively immobile (Bartlett and Kimble, 1976a); the hexavalent forms are considered as unstable and quite mobile in soils (Bartlett and Kimble, 1976b).

Trivalent chromium, in the Cr^{+3} form has been found to be essential for human and animal nutrition. As for plant nutrition, trivalent chromium has not been proven to be essential, but there are some reports that it may be stimulatory, in low concentrations to some species of plants (Turner and Rust, 1971). Hexavalent chromium, on the other hand, is known to be toxic, at low concentrations to both plants and animals (Bartlett and Kimble, 1976b).

Griffin et al. (1977) studied the effects of pH and the physical-chemical properties of clay minerals on the adsorption of chromium by montmorillonite and kaolinite. They found that the adsorption of Cr(III) increased with an increase in pH, and that the adsorption of

Cr(VI) decreased as the pH was increased, and no adsorption of Cr(VI) occured above pH 8.5. Montmorillonite was found to adsorb more Cr(III) and Cr(VI) than kaolinite due to its higher CEC and a difference in the probable number of available adsorption sites, based on structural differences and external surface areas of the clays.

Oxides are always present in soils and they control many reactions, including the adsorption and oxidation state of chromium. Bartlett and James (1979) found that when Cr(III) is adsorbed by manganese oxides it can undergo oxidation and be converted to Cr(VI). Manganese oxides have large surface areas and high negative charges which allow them to have high adsorptive capasities for many elements. Not much is known about adsorption of chromium by iron oxides.

The purpose of this study was to investigate the adsorption and subsequent release of chromium by soil minerals, in order to assess its potential availability to plants.

METHODS AND MATERIALS

The oxides used in this study were haematite (Fe_2O_3, 400 mesh) and birnesite (MnO_2, 400 mesh). The clay minerals used were vermiculite (Transvaal) and montmorillonite (Upton, Wyoming).

Two 10^{-3} M solutions of $CrCl_3 \cdot 6H_2O$ were prepared and their pH were adjusted to 4 or 5, using 0.1 M HCl or 0.1 M NaOH.

250 mg samples of each of the oxides and one gram samples of each of the clay minerals were used in the adsorption study. The experiment was conducted in duplicate. Controls with no oxides or clay minerals were also used.

20 ml of each of the chromium solutions were added to the soil mineral samples. They were shaken for 2 hours and then were allowed to stand for 20 hours. The suspensions were then centrifuged for 30 minutes at 24,000 g.

The supernatants collected were analyzed for total chromium by atomic absorption spectroscopy, and also for Cr(VI) using a modified method of Bartlett and Kimble (1976a). The absorbance was read on a spectrophotometer at 540 nm.

The residues were washed five times, with 20 ml of deionized water to remove excess free chromium.

The residues, now containing only adsorbed chromium were washed twice with 20 ml of 0.1 M KH_2PO_4 and the supernatants were collected. Two final washings of the residues with 20 ml of a 0.5 M $CaCl_2$ solution followed by 10 ml of the same solution were conducted. The supernatants collected were analyzed for total chromium and Cr(VI).

RESULTS AND DISCUSSION

The oxides, haematite and birnesite, adsorb more trivalent and hexavalent chromium than the clay minerals, montmorillonite and

vermiculite (Table 1). This is due to different bonding mechanisms, larger surface areas, and more reactive surfaces on the oxides. The amount of chromium adsorbed by these soil minerals can be ranked in the following decreasing order in their ability to adsorb chromium: haematite > birnesite > montmorillonite > vermiculite. Also, in terms of the percentage of the initial amount of chromium that was added to these soil minerals, Cr(III) was adsorbed more than Cr(VI).

Table 1. Adsorption, desorption and oxidation of Cr by minerals.

Minerals and Cr solution	pH	Total Cr adsorbed	Cr extracted by 0.1M KH_2PO_4		Cr extracted by 0.5M $CaCl_2$
			Total	as Cr(VI)	
		----------	$\mu g\ Cr.g^{-1}$ mineral		----------
Haematite + Cr(III)	4	1120	0	0	0
"	5	1128	0	0	0
Haematite + Cr(VI)	4	905	907	807	0
"	5	800	796	749	0
Birnesite + CR(III)	4	712	33	24	0
"	5	560	29	30	0
Birnesite + Cr(VI)	4	670	172	180	0
"	5	340	23	23	0
Vermiculite + Cr(III)	4	*	*	*	0
"	5	*	1.5	*	0
Vermiculite + Cr(VI)	4	79	10	22	0
"	5	50	8	8	0
Montmorillonite + Cr(III)	4	100	58	*	47
"	5	65	32	*	35
Montmorillonite + Cr(VI)	4	550	19	18	23
"	5	218	38	41	9

*indicates that no Cr could be detected in the supernatants (both precipitation and adsorption are suspected but this has to be clarified.

As the pH increased from 4 to 5, the pH dependent negative charge increased, and thus the adsorption of Cr(VI) (an anion) decreased (Table 1). The amount of adsorbed Cr(VI) that was extracted by KH_2PO_4 should have also increased with pH (Bartlett and Kimble, 1976b) but our data did not show this in its entirity.

The strength with which the oxides held Cr(VI) was less than that of the clay minerals (Table 1) since there was more adsorbed Cr(VI) displaced from the oxides by the 0.1 M KH_2PO_4 solution. The release of adsorbed Cr(VI) from the clay minerals increased with pH, due to an

increase in the negative charge on their surfaces. Adsorbed Cr(VI) was easily displaced by 0.5 M $CaCl_2$ only from montmorillonite.

The results in Table 1 also show that trivalent chromium was not greatly adsorbed by the clay minerals despite their high CEC. As well, the oxides hold Cr(III) much tighter than the clay minerals. Of the Cr(III) adsorbed by haematite, none was released during the extraction with KH_2PO_4 and $CaCl_2$ solutions, about 5% was released from birnesite, and aprroximately 50% of the Cr(III) could be extracted from montmorillonite by KH_2PO_4. The Cr(III) adsorbed by montmorillonite was least strongly bound since a subsequent extraction with $CaCl_2$ displaced all of the remaining adsorbed Cr(III).

Trivalent chromium is potentially toxic if it is oxidized to Cr(VI). For the soil minerals selected only birnesite was observed to have oxidized some of the adsorbed Cr(III) to Cr(VI), and the majority of Cr(VI) so formed could by extracted by KH_2PO_4 (Table 2). Soils inwhich birnesite may be present (eg. acid-sulphate soils) in significant amounts may therefore show a high propensity to convert Cr(III) to Cr(VI), at the same time enhancing the level of chromium toxicity. It is believed that if this adsorbed Cr(VI) is displaced from the oxide by an ion such as phosphate, it can be available to plants.

Table 2. Extraction of adsorbed Cr(VI) that had formed from Cr(III) by KH_2PO_4 and $CaCl_2$ solutions.

Minerals and Cr solution	pH	Extracted by 0.1M KH_2PO_4		Extracted by 0.1M $CaCl_2$	
		Total	As Cr(VI)	Total	As Cr(VI)
		μg Cr/g mineral			
Haematite + Cr(III)	4	0	0	0	0
"	5	0	0	0	0
Birnesite + Cr(III)	4	33	24	0	0
"	5	29	30	0	0
Vermiculite + Cr(III)	4	0	0	0	0
"	5	0	0	0	0
Montmorillonite + Cr(III)	4	58	0	47	0
"	5	32	0	35	0

CONCLUSIONS

It is a known fact that Cr(VI) is more mobile in soils than Cr(III) and therefore if chromium is present in the soil as Cr (VI), it can be expected to be toxic. Any system which oxidizes Cr(III) to Cr(VI) will increase the level of chromium toxicity; in our study we found manganese dioxide to be such a system.

There is the potential of chromium toxicity in soils that contain birnesite because Cr(III) is capable of being oxidized to Cr(VI) during adsorption, and if this adsorbed Cr(VI) is displaced from this oxide by an ion such as phosphate, it will become mobile and may be taken up by plants.

REFERENCES

Bartlett, R. and B. James. 1979. Behavior of chromium in soils: III.Oxidation. J.Environ.Qual. 8:31-35.

Bartlett, R.J. and J.M. Kimble. 1976a. Behavior of chromium in soils: I.Trivalent forms. J.Environ.Qual. 4:379-383.

Bartlett, R.J. and J.M. Kimble. 1976b. Behavior of chromium in soils: II.Hexavalent forms. J.Environ.Qual. 5:383-386.

Griffin, R.A., A.K. Au., and R.R. Frost. 1977. Effect of pH on adsorption of chromium from landfill-leachate by clay minerals. J.Environ.Sci.Health. A12:431-449.

Turner, M.A. and R.H. Rust. 1971. Effects of chromium on growth and mineral nutrition of soyabeans. Soil Sci.Soc. Amer.Proc. 35:755-758.

The Availability and Uptake of Copper and Zinc Adsorbed on Iron Oxides

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INTRODUCTION

Recent studies on the copper and zinc fertility status of agricultural soils in the prairie regions (Kruger et al. 1985, Singh et al. 1987, unpublished data Dept. of Soil Science) show that deficiencies of these micronutrients according to the DTPA soil test may be more common than is believed and varies with soil type and the crop grown. Attempts to alleviate the deficiencies have produced variable results due to differences in the calibration of availability indices against yield responses and perhaps the form in which the micronutrients were applied to soil.

By virtue of their status as micronutrients, Cu and Zn, have to be supplied to plants in sufficient quantities and yet non-toxic concentrations. The use of compounds such as the sulphates of Cu and Zn presents some special problems with regard to their mixability with other fertilizers as well as the possibility of too high concentration in toxic bands. Organic chelates are commonly used as micronutrient sources but may be expensive to use.

The rationale in choosing iron oxides as carriers of Cu and Zn for crop utilization are several: The oxides of iron are abundant as by products of many industries such as those that use electric arc furnaces (EAF dusts) or can be prepared easily in the laboratory. The pH dependent adsorption of Cu and Zn by iron oxides is well known (e.g. Kalbasi et al. 1978) and can be quite appreciable. It is conceivable that the concentration of Cu and Zn on the surfaces of the iron oxides by adsorption may be followed by a release during the growing season that is sufficient to meet crop demand without giving rise to toxicities. The objectives of this study was to investigate the role of two iron oxides, crystalline haematite and amorphous iron oxide, as Cu and Zn carriers in soil for the nutrition of wheat.

MATERIALS AND METHODS

Preparation and characterization of oxides:
Two iron oxides, each ground to pass a 400 mesh sieve were used in the study. The crystalline haematite was purchased from Fisher Scientific Co. The amorphous iron oxide was prepared in the laboratory by dissolving 500 g of $FeCl_3$ in water and adjusting the pH with 5.0 mol L^{-1} NaOH until the final suspension pH was 7.0 in a total volume of 2.0 litres. The precipitate was collected by filtration through Whatman #1 filter paper, washed thoroughly with deionized water, dried on plastic trays, then ground and sieved before further use. The term 'oxide' is used here to designate true oxides such as haematite (Fe_2O_3) as well as hydroxides ($Fe(OH)_3$) and other more complex compounds such as $(Fe(OH)_3Cl_3)^{3-}$ which may be present in the amorphous sample.

The iron oxides were characterized by specific area measurements and surface charge determination as described elsewhere (Goh et al. 1986).

Three litres of $CuCl_2$ or $ZnCl_2$ solutions, each 40 ug.ml-1 in concentration were added to 100g portions of haematite or amorphous iron oxide in beakers. The initial solution pH was adjusted to 6.0 in $CuCl_2$ and 6.5 for $ZnCl_2$. The suspensions were filtered after 24 hours and fresh solutions of $CuCl_2$ and $ZnCl_2$ were added. Since adsorption of Zn or Cu by oxides results in a net release of protons (Kalbasi et al. 1978, McBride 1982, Kinniburgh 1983), the iron oxides were deemed to have reached their adsorption maxima when no further drop in pH of the leachate was recorded. Ten cycles of equilibration were necessary in this experiment before saturation with Cu or Zn was achieved. The solid phases were then rinsed with 5 litres of deionized water and half of each iron oxide was collected and air-dried. These fractions were considered to contain specifically plus non-specifically adsorbed (S+N) Cu or Zn. The remainder of each iron oxide was washed with 1 litre of 1 mol L^{-1} $CaCl_2$ followed by 4 litres of deionized water. The fractions thus collected were designated as containing specifically adsorbed (S) micronutrients. The total amounts of Cu or Zn from the (S+N) and (S) samples of haematite and amorphous iron oxide were measured after total dissolution of the oxides in HCl (Goh et al. 1987). In addition, 500 mg of each sample were sequentially extracted with 25 ml of 1 mol. L^{-1} $CaCl_2$ or .005 mol. L^{-1} DTPA to assess the release of adsorbed micronutrients over time. The Cu, Zn and Fe content of the extracts were measured by atomic absorption spectroscopy.

Growth chamber experiment:

A growth chamber study was conducted in three replicates using a randomized complete block design with four wheat plants (var. Columbus) per pot. Treatments consisted of control (no micronutrients added), micronutrients added as solutions of $CuCl_2$ or $ZnCl_2$, and micronutrients added with iron oxides, each containing either specifically plus non-specifically or specifically adsorbed forms only. The amounts of Cu or Zn added from each source were adjusted so that 5 mg would be added per kilogram of soil. Two kilograms of soil were used in each pot. In addition, adequate amounts of NH_4NO_3, KH_2PO_4 and K_2SO_4 were added to each pot to supply macronutrients. All fertilizer materials were mixed with the soil before potting and planting. The plants were harvested after 45 days of growth. The top dry matter yield, micronutrient concentration in the tops and total uptake by plant tops were measured.

RESULTS AND DISCUSSION

Table 1 shows some selected properties of the haematite and amorphous iron oxide used in this experiment. The data show that the adsorption of Cu is greater than that of Zn by iron oxides. This is consistent with data for aluminum oxides (Goh et al. 1986) and is related to the electronegativities of the two adsorbates. Cu, being more electronegative than Zn is expected to form stronger bonds of greater covalent character with the surfaces of the oxides (Kinniburgh et al 1976). In comparing the amount of adsorption between haematite and amorphous iron oxide, more adsorption is

Table 1. Adsorption of Cu and Zn in Iron Oxide Systems

Treatment	% Cu or Zn	% NS adsorption*	Wt. oxide/ pot (gm)
+Haem. Cu (S + N)	0.38	13	2.63
Haem. Cu (S)	0.33		3.03
Haem. Zn (S + N)	0.22	14	4.55
Haem. Zn (S)	0.19		5.26
+Amor. Cu (S + N)	2.14	25	0.47
Amor. Cu (S)	1.60		0.63
Amor. Zn (S + N)	0.67	18	1.49
Amor. Zn (S)	0.55		1.82

*% Non-specific adsorption = % in (S + N) - (S)/(S + N) x 100
+Specific surface areas: Haematite = 7,020 $m^2.kg^{-1}$
Amorphous iron oxide = 11,780 $m^2.kg^{-1}$

Table 2. Extraction of Cu and Zn from Iron Oxides

Treatment	DTPA soil test* (mg. kg^{-1} soil)	% Extraction		
		DTPA	$CaCl_2$	Total
Haem. Cu (S + N)	0.80	54.4	1.8	56.2
Haem. Cu (S)	1.16	62.2	1.9	64.1
Haem. Zn (S + N)	1.17	100.0	7.9	100.0
Haem. Zn (S)	0.23	86.2	9.2	95.4
Amor. Cu (S + N)	0.59	32.8	0.3	33.1
Amor. Cu (S)	0.45	28.2	0.4	28.6
Amor. Zn (S + N)	0.75	49.9	5.3	55.2
Amor. Zn (S)	0.66	55.1	6.2	61.3

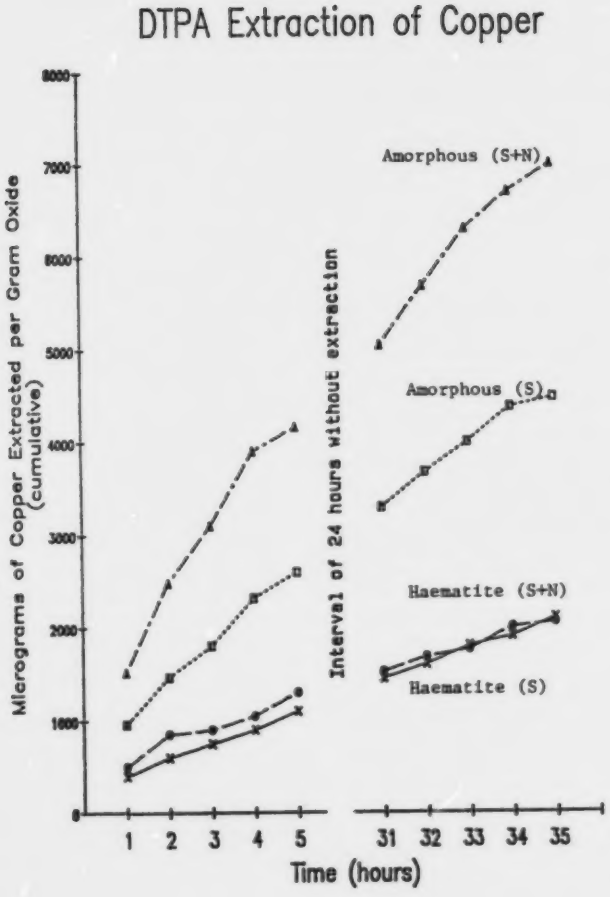
*DTPA - extractable micronutrient in soil
= micronutrients extracted after 2 hours (µg/g) x wt. oxide (g)/wt. soil (kg)

exhibited by the latter (Table 1). This is no doubt due to its higher specific surface area plus the fact that its amorphous nature gives rise to distorted surfaces with more exposed edge groups which are capable of interacting both specifically and non-specifically with Cu and Zn. The points of zero charge (PZC) were determined to be 8.9 and 6.0 for haematite and amorphous iron oxide respectively. The PZC for haematite coincides with that quoted by others (Parks and de Bruyn 1962) but that of the amorphous iron oxide appears to be shifted to the acidic range. It is likely that the amorphous iron oxide contains Cl- as impurities since anions are known to reduce the PZC of oxides (Kwong and Huang 1979, Goh et al. 1986). The combination of a lower value in PZC and its non-crystalline structure would be expected to be manifested in differences in adsorption characteristics between this and the crystalline haematite. At pH values lower than 5.9, the amorphous iron oxide exceeded haematite in net positive charge, again due to a high concentration of exposed edge groups capable of adsorbing potential determining ions (data not shown). A sharp drop in net surface positive charge of amorphous iron oxide with increasing pH with a concurrent sharp increase in negative charge was observed. In contrast, haematite surfaces had net positive charge over the entire range of pH at which the adsorption of Cu and Zn were carried out. In other words, a larger amount of non-specific (i.e. electrostatic) adsorption can be expected in amorphous iron oxide than in haematite. The adsorption data in Table 1 corroborates the theory. Thus it is observed that the difference between (S+N) and (S) adsorption data for Cu and Zn are greater with correspondingly larger values for percentage of non-specific adsorption in amorphous iron oxide than in haematite.

The extraction of Cu and Zn by DTPA showed that more Cu than Zn was extracted from the oxides over time. The data also show that the Cu and Zn supplying power is different from the various sources, namely that amorphous iron oxide released more Cu and Zn than haematite and the (S+N) forms usually exceeded the (S) forms in supplying power (e.g. Fig.1 for Cu). The exception was Cu adsorbed on haematite where no difference in DTPA extractable Cu was measured between the (S+N) and (S) forms. However, when the amounts of Cu and Zn extracted by DTPA after two hours is calculated on a soil basis, with a correction for the weight of iron oxides added to each pot, the total amount of Cu and Zn supplied to the soil by haematite usually exceeded that supplied by amorphous iron oxide (Table 2). These DTPA test values indicate that with the exception of the haematite system containing specifically adsorbed Zn only, all the treatments supplied adequate amounts of Cu or Zn to the plants according to the critical values established by Kruger et al. (1985) for Cu and Lindsay and Norvell (1978) for Zn.

The extraction of Cu and Zn by 1 mol L^{-1} $CaCl_2$ was expected to displace the electrostatically bonded forms only. Despite the high ionic strength of the $CaCl_2$ extractant and the ten sequential, hourly extractions by DTPA and $CaCl_2$, the adsorbed Cu and Zn were usually not completely extracted (Table 2). These extraction data show that iron oxides have a good potential to supply Cu and Zn in small quantities over time and therefore have implications on their use as slow to intermediate release Cu and Zn carriers in soil.
Furthermore, measurements of the Fe/Cu and Fe/Zn ratios in each DTPA

Figure 1.


DTPA Extraction of Copper
Micrograms of Copper Extracted per Gram Oxide (cumulative)
8000
7000
6000
5000
4000
3000
2000
1000
0
Amorphous (S+N)
Amorphous (S)
Haematite (S+N)
Haematite (S)
Interval of 24 hours without extraction
1
2
3
4
5
31
32
33
34
35
Time (hours)

extract (data not shown) revealed that the ratios decreased at each subsequent extraction on haematite systems and increased in the amorphous iron oxide systems. This may mean that haematite is a slow release and amorphous iron oxide is an intermediate rate supplier.

The top yields of wheat were not significantly different among treatments (Table 3). In spite of the apparently better growth of the plants in the control treatment, the concentrations and uptake of Cu and Zn were lower in the control than in all other treatments. The tissue concentration of Cu in the control plants were higher than the critical minimum for deficiency in wheat (Kruger et al. 1985) but that of Zn appeared to be marginally deficient (Radjagukguk et al. 1980). The non-significant top yield responses to Cu and Zn are not by themselves sufficient to negate the role of Cu and Zn in plant metabolism. It can be expected that the greater uptake of these micronutrients from the oxide sources and the accumulation of the same to sufficient, but non-toxic levels in plants, could later be translated to greater plant vigour, higher grain yields, better grain filling and protein content. Moreover, the concentration of Cu and Zn in plant tops may enhance their feed quality to livestock (Stewart et al. 1979).

There was no appreciable difference in the uptake by wheat of Cu and Zn supplied either in the (S+N) or (S) forms from amorphous iron oxide and haematite (Table 3). Even though the extraction data in Table 2 show that the percentage of adsorbed micronutrients that can be extracted by DTPA and $CaCl_2$ from haematite exceeded that from the amorphous iron oxide, the uptake of Cu from the two oxides was not greatly different. However, uptake of Zn from amorphous iron oxide was greater than from haematite. The uptake data (Table 3) therefore point out that while extraction data (Table 2) can be used to evaluate sufficiency or deficiency of micronutrients, inferences as to the ranking of the supplying power of these oxides in soil should be made with some caution.

Cu did not strongly inhibit the absorption of Zn by wheat and vice-versa. This is contrary to the observations of others (Schmid et al. 1965, Bowen 1969) who interpreted the absence of synergistic effects as competition between Cu and Zn for the same absorption mechanism. The data (Table 3) also show that when wheat utilizes (S)-adsorbed Zn from the oxides, the uptake of Cu is reduced to about 75% of that in the control as well as the (S+N)-adsorbed Zn sources. The literature (Lingle et al. 1963) reports that increased uptake of Cu and Zn is accompanied by a reduction in concentration and uptake of Fe by plants. Results from our experiment (Table 4) show that all sources of Cu or Zn used reduced total plant uptake of Fe but the tissue concentration of Fe was reduced only when Cu and Zn were supplied as adsorbed forms. This was quite surprising since our extraction data had indicated that some Fe was always released when Cu and Zn was extracted from the iron oxides by DTPA. However, the reduction in tissue concentration of Fe did not cause Fe deficiency but on the contrary may indicate that even though the carriers of Cu and Zn were the oxides of iron, Fe toxicity need not have to be a concern in this study.

Table 3.
Effect of treatments on yields, concentrations and uptake of Cu and Zn

Treatment	Yield (g)	Cu		Zn	
		Conc.*	Uptake**	Conc.	Uptake
Control	2.60	3.58	9.31	14.75	38.35
$CuCl_2$	1.83	6.25	11.44	17.42	31.88
$ZnCl_2$	2.04	3.33	6.79	37.58	76.66
Amor. Cu (S + N)	2.18	5.50	11.99	14.50	31.61
" (S)	2.00	5.83	11.66	13.58	27.16
Haem. Cu (S + N)	2.34	5.92	13.85	14.08	32.95
" (S)	2.28	6.88	15.69	14.63	33.36
Amor. Zn (S + N)	2.20	4.67	10.27	26.67	58.67
" (S)	1.89	4.00	7.56	31.92	60.33
Haem. Zn (S + N)	2.40	4.33	10.39	20.25	48.60
" (S)	1.77	4.33	7.66	22.33	39.52

*Conc. = $\mu g.g^{-1}$
**Uptake = μg

Table 4.
Effect of oxide treatments on Fe nutrition of wheat

Treatment	Fe	
	Conc. ($\mu g\ g^{-1}$)	Uptake (μg)
Control	115.50	300.30
$CuCl_2$	103.08	188.64
$ZnCl_2$	115.25	235.11
Amor. Cu (S + N)	87.58	190.92
" (S)	84.75	169.50
Haem. Cu (S + N)	95.92	224.45
" (S)	80.88	184.41
Amor. Zn (S + N)	79.08	173.98
" (S)	98.17	185.54
Haem. Zn (S + N)	83.75	201.00
"	106.42	188.36

CONCLUSION

This study has shown that the surface chemistry of amorphous iron oxides and the more crystalline haematite predisposes these materials to adsorb micronutrients, Cu and Zn. The availability of the micronutrients and their role in the nutrition of wheat indicate that both specifically and specifically plus non-specifically adsorbed Cu and Zn on iron oxides are similar and can be exploited as slow to intermediate release fertilizer sources.

REFERENCES

Bowen, J.E. 1969. Absorption of copper, zinc, and manganese by sugar cane tissue. Plant Physiol. 44:255-261.

Goh, Tee Boon, A. Violante and P.M. Huang. 1986. Influence of tannic acid on retention of copper and zinc by aluminum precipitation products. Soil Sci. Soc. Am. J. 50:820-825.

Goh, Tee Boon, P.M. Huang, M.J. Dudas and S. Pavluk. 1987. Effect of iron on the nature of precipitation products of aluminum. Can. J. Soil Sci. 67:135-145.

Kalbasi, M., G.J. Racz and L.A. Loewen-Rudgers. 1978. Mechanism of zinc adsorption by iron and aluminum oxides. Soil Sci. 125:146-150.

Kinniburgh, D.G. 1983. The H^+/M^{2+} exchange stoichiometry of calcium and zinc adsorption by ferrihydrite. J. Soil Sci. 34:759-768.

Kinniburgh, D.G., M.L. Jackson and J.K. Syers. 1976. Adsorption of alkaline earth, transition and heavy metal cations by hydrous oxide gels of iron and aluminum. Soil Sci. Soc. Am. J. 40:796-799.

Kruger, G.A., R.E. Karamanos and J.P. Singh. 1985. The copper fertility of Saskatchewan soils. Can. J. Soil Sci. 65:89-99.

Kwong, K.F. and P.M. Huang. 1979. Surface reactivity of aluminum hydroxides precipitated in the presence of low molecular weight organic acids. Soil Sci. Soc. Am. J. 43:1107-1113.

Lindsay, W.L. and W.A. Norvell. 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. Soil Sci. Soc. Am.J. 42:421-428.

Lingle, J.C., L.O. Tiffin and J.C. Brown. 1963. Iron uptake-transport of soybeans as influenced by other cations. Plant Physiol. 38:71-76.

McBride, M.B. 1982. Cu^{2+} adsorption characteristics of aluminum hydroxides and oxyhydroxides. Clays Clay Miner. 30:21-28.

Parks, G.A. and P.L. de Bruyn. 1962. The zero point of charge of oxides. J. Phys. Chem. 66:967-973.

Radjagukguk, B., D.G. Edwards and L.C. Bell. 1980. Zinc availability to young wheat plants in Darling Downs black earths. Aust. J. Agric. Res. 31:1083-1096.

Schmid, W.E., H.P. Haag and E. Epstein. 1965. Absorption of zinc by excised barley roots. Physiol. Plant. 18:860-869.

Singh, J.P., R.E. Karamanos and J.W.B. Stewart. 1987. The zinc fertility of Saskatchewan soils. Can. J. Soil Sci. 67:103-116.

Stewart, J.W.B., J.O. Moir and V.J. Racz. 1979. Recent work on copper and molybdenum in pastures and soils in Saskatchewan. Proc. Soils and Crops Workshop, Extension Div. Univ. of Sask. pp 172-190.

ZINC INTERACTIONS IN FLAX PRODUCTION

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Flax (Linum usitatissimum L.) is a major crop in Manitoba, being sown on between 200,000 and 500,000 ha each year. Although flax yields of 2200 kg/ha are frequently reported in individual fields, the average yield of flax in Manitoba has only exceeded 1000 kg/ha in 4 years since 1950. While early seeding and improved weed control are extremely important in promoting optimum flax yields, proper fertilizer management is also an important factor.

Micronutrient deficiencies do not generally restrict crop yields in Manitoba. However, of the micronutrients, Zn is the most commonly restrictive on mineral soils. Flax is one of the crops most sensitive to zinc deficiencies. Increased and more efficient use of fertilizer P in flax may increase the possibility of Zn deficiency, by: (a) reactions or antagonism between P and Zn in the soil or plant that restrict Zn availability (b) removal of P deficiency as a limiting factor for yield and (c) restriction of mycorrhizal infection of the roots. Tissue analysis conducted in flax fields in Western Manitoba indicated that Zn levels are frequently at marginal to deficient levels, with levels below 20 ppm occurring in 17 out of 25 sites. Therefore, management of flax for maximum economic yield may require Zn fertilization.

Many of the soils in Manitoba contain high levels of Ca and Mg and have relatively high pH levels. Further, availability of Zn is known to decrease with increasing pH. Therefore, deficiencies of Zn may be more likely on soils high in Ca and Mg than in soils low in these nutrients. This may present a restriction to flax yield on calcareous soils high in Ca and/or Mg.

A growth chamber study examined the effects of P and Zn fertilization on the yield and nutrient uptake of flax grown on soils with varying levels of P, Zn, Ca and Mg. The objectives of the study were to determine:

(1) the effect of Zn and P fertilizer on flax yield studies on a range of soils.

(2) if P fertilization restricted plant utilization of Zn.

(3) which soil factors influence the availability of Zn and P to flax and the likelihood of a yield response to Zn and P fertilization.

Materials and Methods

Eight calcareous chernozemic soils were selected from Western Manitoba, varying in levels of Zn, P, Ca and Mg (Table 1). None of the soils was Zn deficient, according to the standard soil tests.

Three treatments were applied to three replicates of each soil. The treatments were:

(1) Control

(2) 100 kg P ha^{-1}, broadcast and incorporated

(3) 100 kg P plus 12 kg Zn ha^{-1}, broadcast and incorporated

The P was applied as ammonium phosphate ($NH_4H_2PO_4$) and the Zn was applied as zinc sulphate ($ZnSO_4$). The Zn was dissolved in water, sprayed onto the soil, and mixed thoroughly. The P and other nutrients were applied in solid form. Nitrogen and sulphur were applied as

ammonium nitrate (NH_4NO_3) and ammonium sulphate ($(NH_4)_2SO_4$) to balance the N and S applied with the P and Zn.

Plants were grown in four kg of soils in 15 x 15 x 20 cm wooden pots lined with plastic. The soils were treated with an overall addition of N, K and S, which was blended thoroughly with the soil. Twenty seeds were sown 1.0 cm deep and the soils were watered to field capacity with No-Damp solution, to prevent damping off. The soil surface was kept damp until the seedlings emerged, after which the soils were watered to field capacity whenever the moisture content decreased to 70% of field capacity. Seedlings were thinned to 12 after emergence and to 6 per pot after four weeks of growth. Additional N was applied after four weeks of growth to ensure that N did not become restricting.

The above ground portion of the plants were harvested after eight weeks of growth, at early bloom and analyzed for P, Zn, Ca and Mg.

Results

(1) Response to fertilization

(a) Dry matter yield

There was a significant response to P applied alone in three of the eight soils and an additional response to Zn + P in five soils. This does not necessarily indicate that a Zn response would occur on these soils in the field. Plants grown in growth chamber studies may be more susceptible to Zn deficiencies than field grown plants. However, it may be worthwhile to evaluate the responsiveness of flax to Zn on some of these soils in field studies.

Several patterns of response occurred. Soils 2 and 3 showed no response to either Zn or P fertilization, indicating that yield was limited by some factor other than Zn or P. Soil 5 showed a response to P and no additional response to Zn. This soil was apparently adequately supplied with Zn but yields were restricted by a P deficiency. Soils 6 and 7 did not respond to P alone but showed a large response when both Zn and P were applied. These soils were apparently deficient in Zn. Soils 1, 4 and 8 showed a small increase in yield with added P and a further increase when Zn was applied. These soils were apparently deficient in both P and Zn.

(b)Tissue nutrient levels

Phosphorus concentration in the tissue increased with the application of P (figure 2). Application of Zn with the P decreased the tissue concentration of P as compared to the concentration with P applied alone. The uptake of P followed the same patterns (figure 3), although the depression in P uptake with the addition of Zn was proportionally less than the depression in tissue concentration.

Zinc concentration in the tissue was generally reduced to some extent by the application of P and increased by the application of P + Zn (figure 4). Uptake of Zn was generally unaffected or slightly decreased by the application of P alone, with the exception of soils 4 and 8 (figure 5). In these soils, application of P increased uptake of Zn, presumably because the increase in growth due to the P allowed the plant to increase the uptake of the Zn available in the soil. Uptake of Zn increased when Zn was applied with the P, with the exception of soil 8, where uptake of Zn was not influenced by applied Zn. The applied Zn did not appear to be taken up by the plant in this

soil, for some reason, although it did result in a yield increase.

(2) Effect of Soil Composition

Soils were analyzed for Zn, P, Mg, Ca, pH and conductivity and correlation coefficients among these factors were calculated (Table 2). Zinc level was not correlated with any of the other soil factors measured. Phosphorus level decreased with increasing Mg content and increased with increasing Ca:Mg ratio. Calcium level was positively related to the pH and conductance of the soil and pH and conductance were positively related to one another. The ratio of Ca/Mg was most strongly influenced by Mg content of the soil while the ratio of Zn/P was positively related to Ca level in the soil.

Correlation coefficients among yield parameters and soil variables are given in Table 3. These give the simple observed relationship between any two variables, without considering the effects of any other factors. Yield of the control increased as Zn in the soil increased (figure 6). Yield of the control was not correlated with the level of P or Ca in the soil but was negatively related to Mg level in the soil although it appeared to follow a curvilinear relationship, increasing initially as Mg level increased and then decreasing at very high Mg levels (figure 7).

The regression equation best describing yield of the control treatments in relation to soil composition was:

Yield = 94.5 - 13.38 pH + 81.89 Zn/P + 1.08 Ca/Hg (R^2=0.84 $p<0.0001$, fig. 8).

As expected, the increase in yield due to applied P decreased as the level of P in the soil increased. Unexpectedly, response to applied P also decreased with increasing levels of Zn in the soil (figure 9, r=-0.61, $p<0.0014$), primarily due to a single highly responsive soil.

The regression equation for increase in yield due to P application was:

Increase = -357.45 + 6.60 Zn - 0.70 P - 0.016 Ca + 54.70 pH + 0.167 conductance (R^2=0.73, $p<0.0001$, fig. 10).

This indicates that when the other factors in the soil are considered, response to applied P does increase as Zn level in the soil increases and decrease as P level in the soil increases, however, the variations in Ca, pH and conductance modify the effects of the Zn and P.

The increase in yield which occurred when both Zn and P were applied decreased as the level of P in the soil increased (figure 11) but was not correlated with Zn or Mg level in the soil.

The regression equation for increase in yield due to Zn + P was:

Increase = -375.21 + 8.76 Zn - 0.876 P - 0.015 Ca + 56.51 pH + 0.166 conductance (R^2=0.87 $p<0.0001$, fig. 12).

This is very similar to the relation for response to application of P alone.

The increase in yield attributable to Zn application, when broadcast P was applied (calculated as yield with applied P + Zn - yield with broadcast P alone) decreased as the level of P in the soils increased and increased as the Zn/P ratio in the soil increased (figure 13, r=-0.74 p<0.0001). This is contrary the expectation of a higher response to applied Zn when P was high and Zn was low. When the multiple regression equation was calculated, the effect of Zn was;

Increase = -7.40 + 0.001 Ca + 52.85 Zn/P (R^2=0.66 p<0.0001) (figure 14).

So, even when the other soil factors were considered, response to Zn still increased as Zn/P ratio increased.

Were the differences in flax response to Zn and P fertilization due to the influence of soil factors on the ability of the plants to utilize Zn and/or P from the soil? Table 4 shows the correlation coefficients between tissue concentration and uptake of Zn and P in the control, and some soil factors, yield of the control and response to fertilization.

There was a strong negative relationship between Zn level in the soil and tissue concentration of Zn. Concentration of Zn in the tissue was negatively correlated with P level in the soil, although when the other soil factors were considered as well the relationship became positive. Concentration of Zn was negatively correlated with Ca/Mg ratio in the soil. Zn uptake by the plant was unrelated to Zn or P level in the soil, but decreased with increasing Mg level and conductance of the soil.

The regression equation for Zn concentration was:

Concentration = 71.9 - 7.19 Zn + 0.176 P + 0.0015 Ca - 0.017 Mg - 0.394 Ca/Mg (R^2=0.87 p<0.0001).

The regression equation for Zn uptake was:

Uptake = 1.79 - 0.0037 P - 0.0012 Mg - 0.182 pH (R^2=0.74 p<0.0001).

These equations indicate that although Zn concentration in the tissue decreased with increasing Zn level in the soil, the uptake of Zn was not affected. Uptake of Zn was depressed by increasing soil P and Mg levels and pH.

Zn level in the soil was not a good indicator of availability of Zn to the plant in these studies. Zinc concentration in the tissue decreased and Zn uptake increased as yield of the control increased. Therefore, as the Zn level in the soil increased, yield increased at a rate greater than the ability of the plant to absorb Zn, leading to dilution of the Zn in the tissue. This type of response may occur when Zn is very deficient and is then referred to as the Piper-Steenbjerg effect. However, the levels of Zn in this study did not seem to be low enough to cause this type of a response.

The yield response of flax to P fertilization alone decreased as P concentration in the tissue and P uptake increased. This would be expected where P deficiencies limited yield. Response to P also

increased as Zn concentration in the tissue increased. This may indicate that the ability of the plant to respond to P increases as the tissue level of Zn increases. Alternately, it may indicate that Zn level in the tissue increases when the yield is restricted due to a P deficiency. Increase in yield due to P + Zn fertilization decreased as tissue concentration of P in the control increased and increased as Zn/P ratio increased. Response to Zn fertilization was not related to tissue Zn/P ratio or tissue concentration or uptake of Zn or P.

Which soils are most likely to respond to applications of Zn and/or P? Response to P increased as pH, conductance and soil Zn levels increased, but decreased as P and Ca content increased. Therefore, a response to P is more likely in soils that are low in P and higher in Zn, pH and conductance. The response to Zn + P followed the same general pattern.

Yield increase due to applied Zn was lower at high concentrations of P and higher at higher soil Zn/P ratios. This is directly opposite to what one would expect. The level of DTPA-extractable Zn in the soil seems to have little relation to the likelihood of a Zn response or to availability of Zn to the plant in these studies. Tissue analysis was also of little help. Factors most closely associated with response to Zn were a high soils Zn/P ratio, a high level of Ca and a high pH in the soil.

Conclusions

(1) Flax responded to Zn and P fertilization in 5 out of 8 Manitoba soils in growth chamber studies. This does not necessarily mean that a response would occur in these soils in the field, as plants in the growht chamber may be more susceptible to Zn deficiencies than field grown plants. Some of these soils are currently being examined in field studies to see if responses do occur.

(2) Phosphorus fertilization consistently restricted Zn concentration in flax tissue and on some soils slightly decreased uptake of Zn by flax.

(3) The increase in yield due to P and to Zn + P fertilization was higher when soil Zn, pH and conductance were high and lower when P and Ca were high. The increase in yield due to Zn applied with P was higher when soil Ca, pH and Zn/P were high.

(4) DTPA extractable Zn levelin soils was not effective in predicting response to Zn fertilization, Zn level in tissue or Zn uptake by plants. Tissue Zn level was also ineffective in predicting response to Zn fertilization.

Table 1: Types and some chemical characteristics of soils used in the study

SOIL	Zn	P	Mg	Ca	PH	Conductance (mhos x 10^{-5})
	mg kg^{-1}					
1. Miniota FSL	1.75	19.50	1798	4428	7.40	17.3
2. Beresford CL	2.60	49.50	291	3075	7.48	9.3
3. Kleyson SiCL	1.83	48.00	646	6642	7.55	44.7
4. Beresford CL	2.25	19.75	921	4305	7.33	16.7
5. Druxman CL	1.22	20.50	394	3526	7.36	11.9
6. Newdale CL	2.99	26.50	672	5986	7.43	28.4
7. Justice CL	3.05	17.50	872	6724	7.71	22.0
8. Beresford CL	1.00	11.50	1159	5986	7.61	29.8

Table 2: Correlation coefficients between soil chemical characteristics in eight Manitoba soils.

	Zn	P	Ca	Mg	pH	Cond	Zn/P	Ca/Mg
Zn	--	ns	ns	ns	ns	ns	0.55**	ns
P	ns	--	ns	-0.55**	ns	ns	-0.61**	0.72***
Ca	ns	ns	--	ns	0.70***	0.84***	0.41*	ns
Mg	ns	-0.55**	ns	--	ns	ns	ns	-0.91***
pH	ns	ns	0.70***	ns	--	0.44*	ns	ns
Cond	ns	ns	0.84***	ns	0.44*	--	ns	ns
Zn/P	0.55**	-0.61**	0.41*	ns	ns	ns	--	ns
Ca/Mg	ns	0.72***	ns	-0.91***	ns	ns	ns	--

Table 3: Flax dry matter yield and response to Zn and P fertilizer as a function of soil chemical composition in eight Manitoba soils.

	Yield of Control	Increase Due to P	Increase Due to P + Zn	Increase Due To Zn
Zn	0.69**	-0.61**	ns	ns
P	ns	-0.44*	-0.70***	-0.45*
Ca	ns	ns	0.55**	0.61**
Mg	-0.50*	ns	ns	ns
pH	ns	ns	0.43*	0.44*
Cond	ns	ns	ns	ns
Zn/P	0.50*	ns	0.51*	0.74***
Ca/P	0.43*	ns	-0.44*	ns

Table 4: Correlation coefficients between flax tissue Zn and P concentration and uptake and some soil chemical characteristics, dry matter yield and response to Zn and P fertilizer in eight Manitoba soils.

	Zn Concentration in Tissue	Zn Uptake	P Concentration in Tissue	P Uptake	Zn/P Ratio
Zn	-0.83***	ns	ns	0.83***	-0.72***
P	-0.41*	ns	0.65**	ns	-0.59**
Ca	ns	ns	ns	ns	ns
Mg	ns	-0.42*	ns	-0.52**	ns
pH	ns	ns	ns	ns	ns
Cond	ns	-0.50*	ns	ns	ns
Zn/P	ns	ns	ns	ns	ns
Ca/Mg	-0.53**	ns	ns	0.57**	-0.43*
Control Yield	-0.69**	0.63**	ns	0.80***	ns
Increase from P	0.64**	ns	ns	-0.68**	0.74***
Increase from P + Zn	ns	ns	-0.50*	ns	0.57**
Increase from Zn	ns	ns	ns	ns	ns

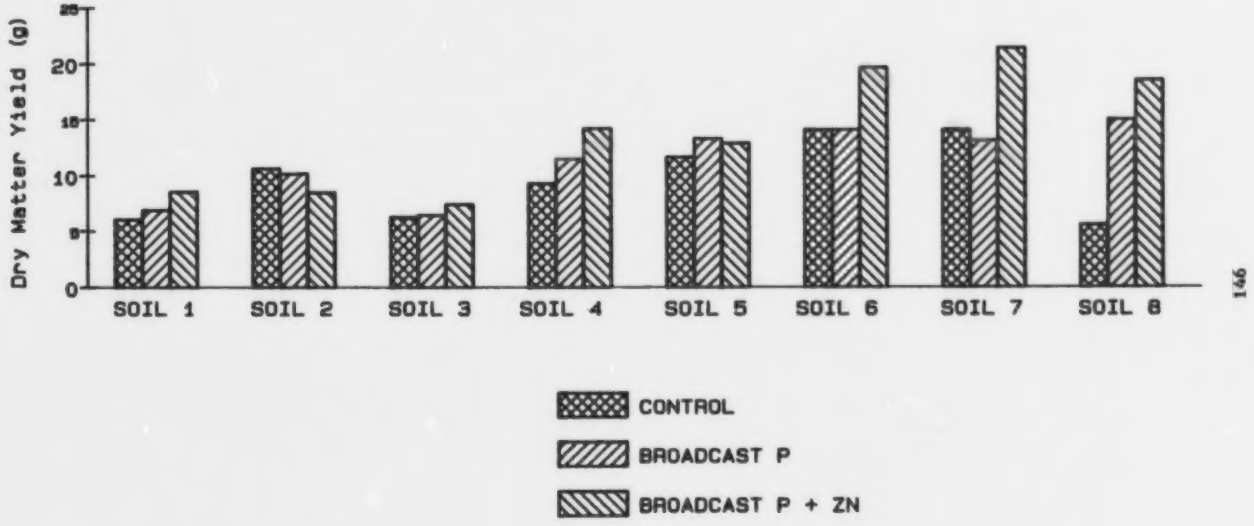

Fig. 1: Dry matter yield of flax grown on eight soils as influenced by Zn and P fertilization

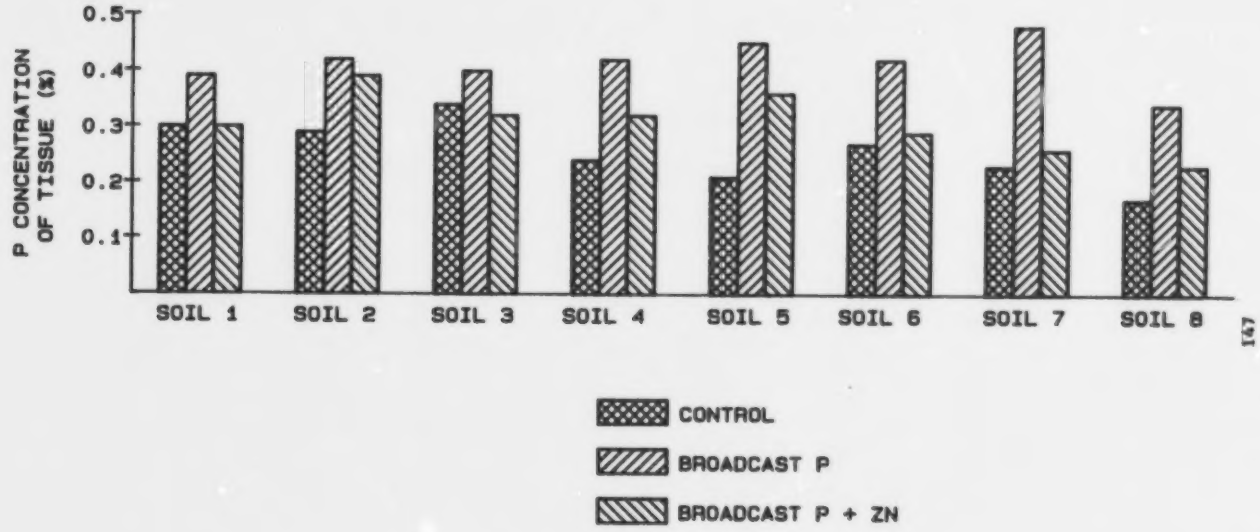

Fig. 2: Concentration of P in the tissue of flax grown on eight soils as influenced by Zn and P fertilization

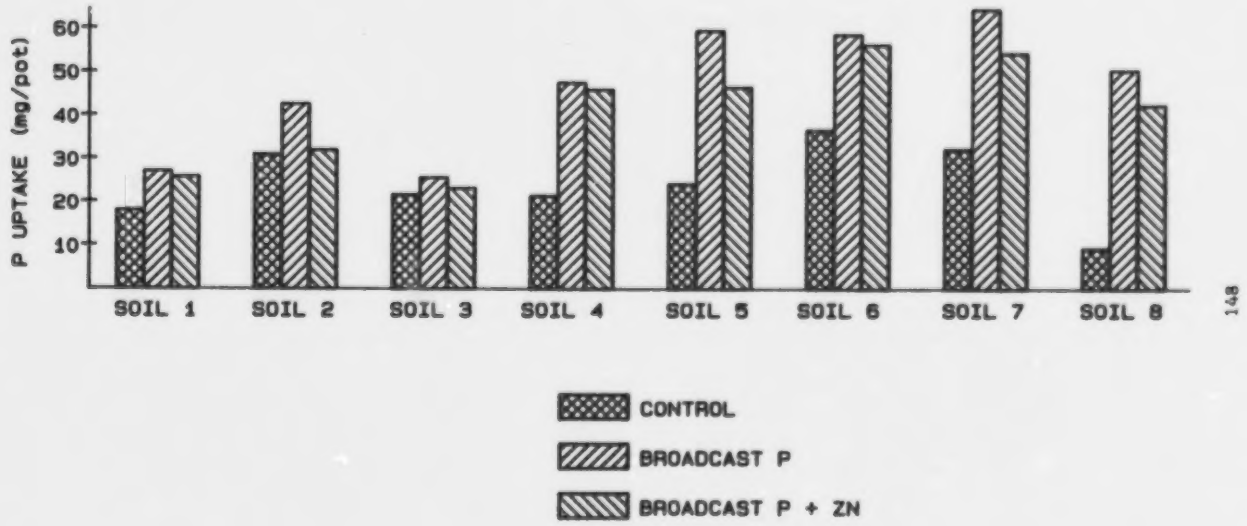

Fig. 3: Uptake of P by flax grown on eight soils as influenced by Zn and P fertilization

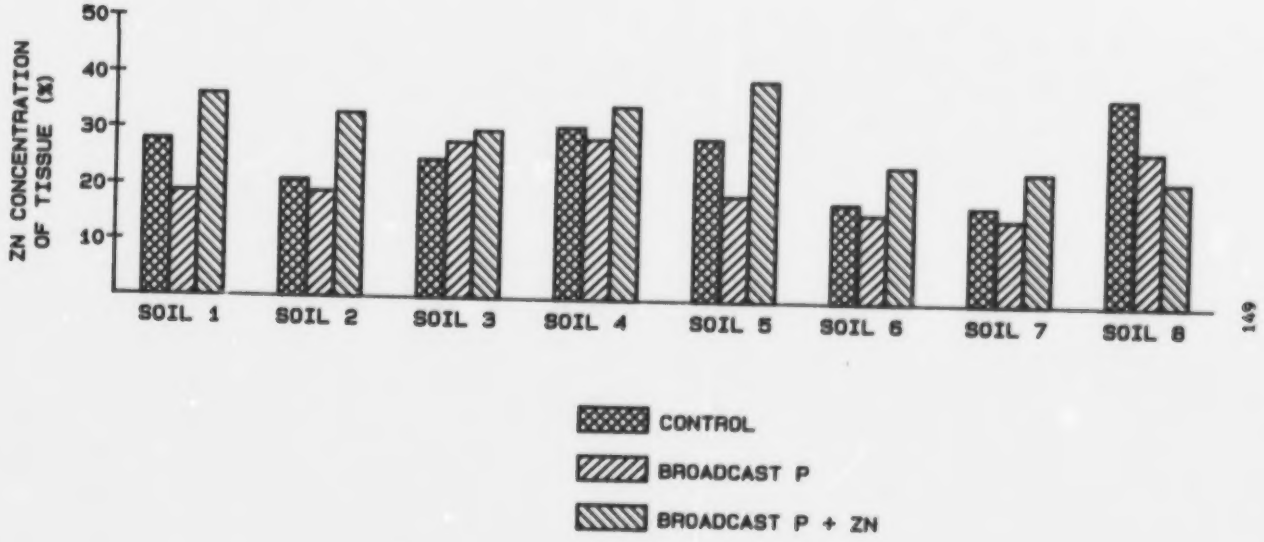

Fig. 4: Concentration of Zn in the tissue of flax grown on eight soils as influenced by Zn and P fertilization

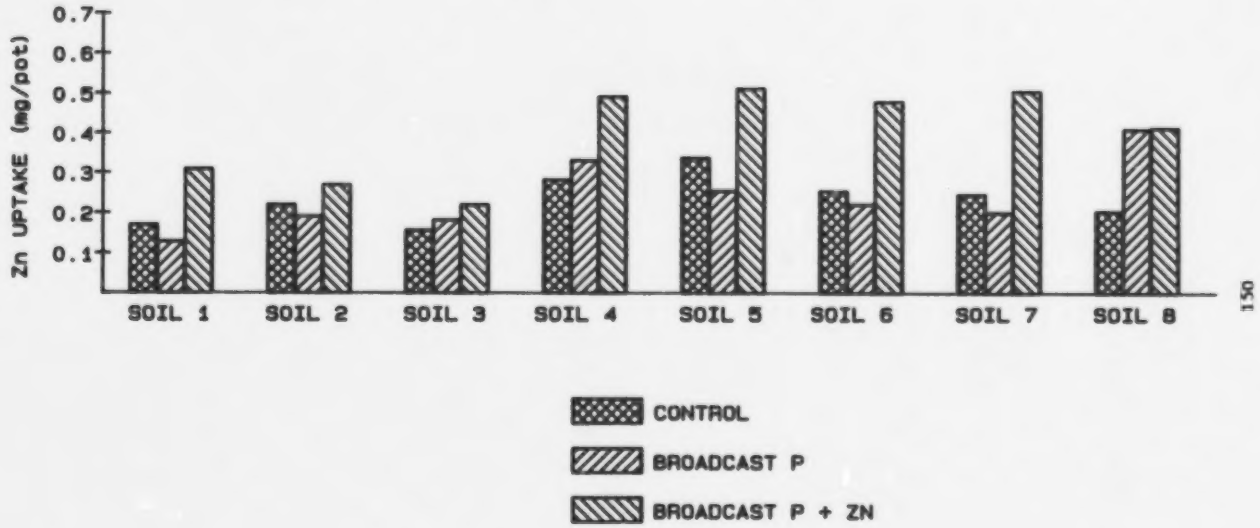

Fig. 5: Uptake of Zn by flax grown on eight soils as influenced by Zn and P fertilization

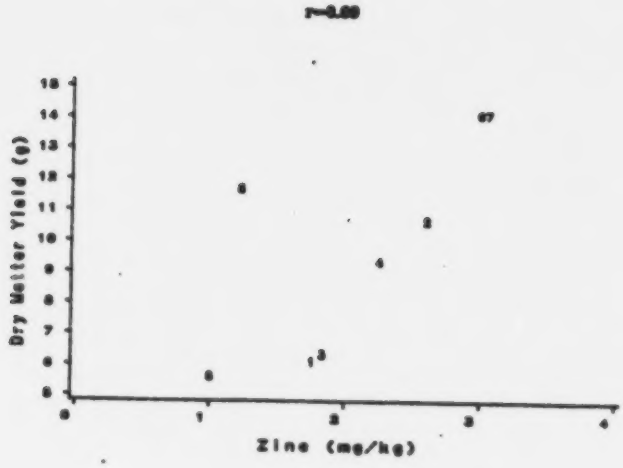

Fig. 6: Flax yield of the control treatment as a function of soil Zn concentration in eight soils

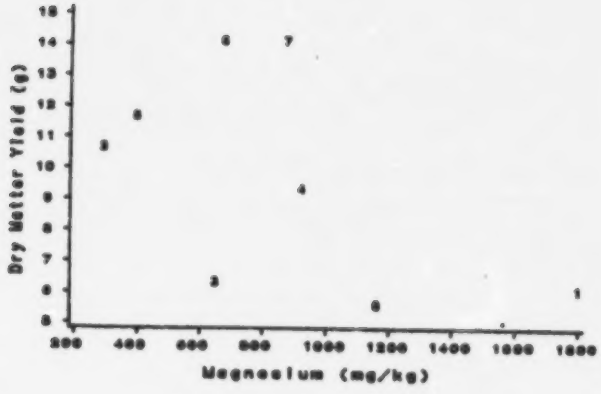

Fig. 7: Flax yield of the control treatment as a function of soil Mg concentration in eight soils

Yield = 84.8 − 13.4 x pH + 81.8 x Zn/P + 1.1 x Ca/Mg
R = 0.84

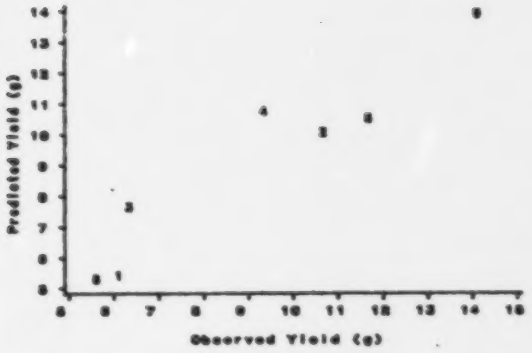

Fig. 8: Predicted dry matter yield as a function of observed dry matter yield of flax on eight soils

r=0.61

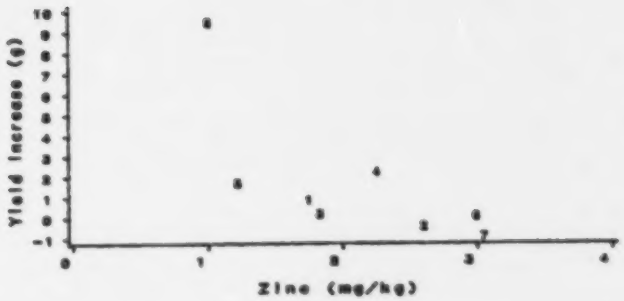

Fig. 9: Increase in flax yield due to P fertilization as a function of soil Zn concentration in eight soils

Increase = -387.8 + 8.6 x Zn - 0.70 x P -0.016 x Ca
+ 84.7 x pH + 0.17 x cond
R = 0.73

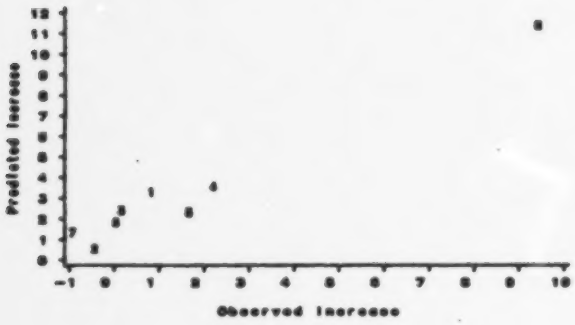

Fig. 10: Predicted increase in yield of flax due to P fertilization as a function of observed yield of flax on eight soils

r=-0.70

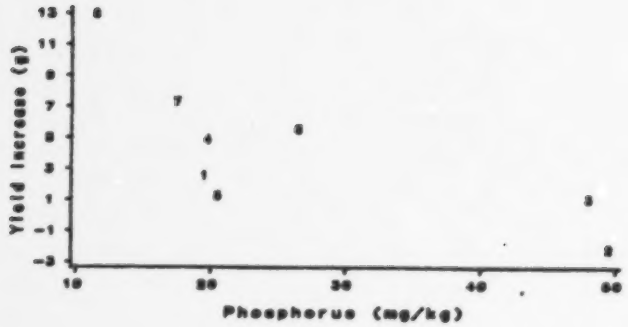

Fig. 11: Increase in flax yield due to Zn + P fertilization as a function of soil P concentration in eight soils

Increase = -378.2 + 8.76 x Zn - 0.88 x P -0.018 x Ca
+ 88.8 x pH + 0.17 x cond
R = 0.87

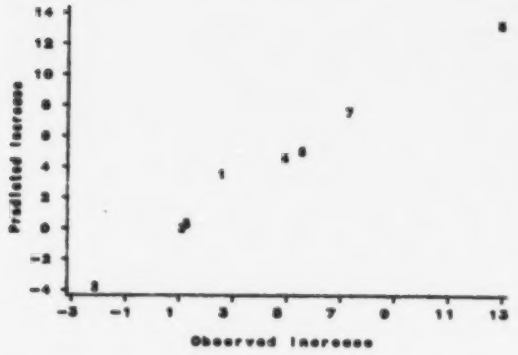

Fig. 12: Predicted increase in yield of flax due to Zn and P fertilization as a function of observed yield of flax on eight soils

r=-0.76

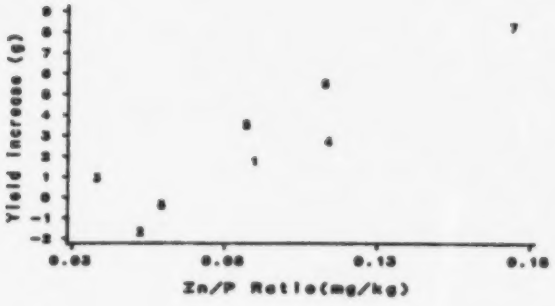

Fig. 13: Increase in flax yield due to Zn fertilization as a function of soil Zn/P ratio in eight soils

EFFECT OF SELECTED N AND P FERTILIZERS ON SOLUBILITY AND MOVEMENT OF Zn FROM $ZnCl_2$ AND ZnEDTA FERTILIZER BANDS

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Introduction

Banding is a widely recommended method of fertilizer application for a wide variety of nutrients. Significant yield increases as well as nutrient uptakes has been reported in many crops when nutrients such as N, P, K as well as S were applied as inorganic fertilizer salts in bands at seeding time. In contrast, Zn uptake from Zn fertilizer bands has been shown to be very limited when it was applied as an inorganic Zn carrier such as $ZnCl_2$ or $ZnSO_4.7H_2O$. Various studies suggested that the extent of root contact with the fertilizer band as well as the Zn concentration in the reaction zone may be the two major factors affecting Zn uptake by many crops. It was believed that when Zn was applied as a band as either $ZnCl_2$ or $ZnSO_4.7H_2O$, Zn uptake from the band was poor primarily due to poor root contact with the fertilizer band. Hedayat et al (1977) demonstrated that Zn uptake by blackbeans from the inorganic Zn carrier, $ZnSO_4.7H_2O$ increased with increasing rates of applied Zn as well as the size of the fertilizer zone. These findings suggest that any attempt to enhance the solubility of Zn in the fertilizer band as well as an increasse in the size of the fertilizer reaction zone will likely enhance Zn uptake from inorganic fertilizer bands.

Reports in the literature suggest that ZnEDTA is more effective in supplying Zn to plants compared to inorganic Zn fertilizers such as $ZnCl_2$ or $ZnSO_4.7H_2O$ when both are applied as fertilizer bands largely due to the greater ability of ZnEDTA to move in soil. Such movement results in a larger size of the Zn fertilized zone. However, limited information is available in the literature to indicate the differences in extent of movement of Zn from inorganic Zn fertilizers and ZnEDTA.

The influence of other fertilizers particularly N and P on the availability of Zn from inorganic Zn fertilizers has also been demonstrated, mainly through differences in Zn uptake by the plant when such fertilizers were included in the Zn fertilizer band. It was believed that the differences in Zn availability observed were largely associated with changes in soil pH due to addition of such carriers. However, additional work is required to quantify such changes particularly as they relate to the solubility as well as Zn movement in Zn fertilizer bands in an attempt to enhance Zn uptake from fertilizer bands. Therefore, in this study some of the most commonly used N and P fertilizers were compared with respect to their effect on solubility and Zn movement from a $ZnCl_2$ and a ZnEDTA fertilizer band.

Materials and Methods

The solubility as well as movement of Zn in $ZnCl_2$ and ZnEDTA fertilizer bands was studied using two soils, a noncalcareous Stockton Fine Sandy Loam of pH 7.2 and a calcareous Almasippi Loamy Fine Sand of pH 8.4 (Table 1).

The effect of selected N and P fertilizers on the solubility as well as movement of Zn from the Zn fertilizer bands was also determined using soil columns sectioned at 0.5 cm intervals. The treatments used in the study were:

1. $ZnCl_2$ Alone
2. $ZnCl_2$ + $(NH_4)_2SO_4$
3. $ZnCl_2$ + Urea
4. $ZnCl_2$ + $NH_4H_2PO_4$ (MAP)
5. ZnEDTA Alone
6. ZnEDTA + $(NH_4)_2SO_4$
7. ZnEDTA + Urea
8. ZnEDTA + $NH_4H_2PO_4$ (MAP)

Both Zn carriers as well as the N and P fertilizers were applied to the top of the wet soil columns as finely ground crystals or powder form. Zinc was applied at a rate of 16 kg/ha while N and P were added at rates equivalent to 80 kg N/ha and 20 kg P/ha applied in the field as fertilizer bands 2.54 cm wide and 36 cm spacing.

Column Preparation

The columns consisted of 20 acrylic rings 0.5 cm in height with an internal diameter of 5.08 cm. The rings were fitted together using a standard electrician tape. A perforated platform was attached to the bottom of the column to support the column as well as provide for adequate air exchange at the bottom of the column. Adequate aeration was also ensured at the top of the column by covering the column top with perforated parafilm.

Each soil was moistened to field capacity moisture content using deionized water and then carefully packed in the columns to achieve an air filled porosity of approximately 28 percent for both soils. To achieve the above air filled porosity the wet bulk density for the noncalcareous soil was maintained at 1.22 g cm^{-3} while that of the calcareous soil was maintained at 1.27 g cm^{-3}.

The various fertilizers were applied to the surface of the columns and the columns incubated for a period of two weeks in a controlled environmental room at a temperature of 20 ± 1°C and a relative humidity of or close to 100 percent. The high relative humidity was essential to minimize evaporative losses from the column surface.

Extraction of the soil columns

The soil columns were sliced into 0.5 cm sections using a sharp knife. An 8.0 g portion of the wet sample from each section was placed in a 50 ml centrifuge bottle and the remaining portion was placed in moisture tins for determination of gravimetric moisture content. Sixteen ml of deionized water was added to the 8.0 g sample. The samples were shaken for one hour and then centrifuged at 10,000 rpm for 20 minutes. The pH of the supernatant was then measured and the concentration of Zn in solution measured using an Atomic Absorption Spectrophotometer.

Results and Discussion

Solubility of Zn in the $ZnCl_2$ Fertilizer Band

The solubility of Zn in the various bands was expressed as the total quantity of Zn extracted by water from the various soil column sections.

Table 1. Some Physical and Chemical Characteristics of the Soils Used.

	Stockton	Almasippi
pH (1:1 soil:H_2O)	7.2	8.4
Inorganic Carbon (%$CaCO_3$)	0.2	4.1
Organic Matter (%)	3.3	2.7
DTPA Extr. Zn ($\mu g\ g^{-1}$)	2.1	0.5
Field Capacity (%)	19.0	22.0
Particle Density (g cm^{-3})	2.48	2.45
Wet Bulk Density (g cm^{-3})	1.22	1.17
Air Filled Porosity (%)	27.8	28.3
Texture	FSL	LFS

Application of $ZnCl_2$ as a fertilizer band to the noncalcareous Stockton soil resulted in remarkably higher amounts of water soluble Zn in the fertilizer band than for the calcareous soil (Table 2 and 3). The amounts of water soluble Zn were very much higher in the noncalcareous soil than in the calcareous soil except for the treatments containing urea in which amounts of soluble Zn were only two fold greater in the noncalcareous than in the calcareous soil. The difference in the Zn solubility between the soils is a function of the reaction product formed. According to Kalbasi et al. (1978) the concentration of Zn in soil solution for a noncalcareous soil is controlled largely by the solubility of $Zn(OH)_2$, which decreases as the pH is increased. On the other hand Zn concentrations in soil solution for a calcareous soil was controlled by the solubility of $ZnCO_3$ and/or $Zn_5(CO_3)_2(OH)_6$ which were found to be the main reaction products when an inorganic Zn fertilizer was applied to a calcareous soil. Therefore, the low concentrations of Zn obtained when $ZnCl_2$ was applied to the calcareous soil may largely be attributed to the high pH (Fig. 1 and 2) as well as precipitation of the Zn as $ZnCO_3$ or $Zn_5(CO_3)_2(OH)_6$ rather than $Zn(OH)_2$.

Addition of N or P fertilizers had very large effects on solubility of Zn in the $ZnCl_2$ fertilizer bands (Table 2). The solubility of Zn in the $ZnCl_2$ fertilizer band was greatly enhanced in both soils by the addition of $(NH_4)_2SO_4$. The slightly lower pH resulting from addition of $(NH_4)_2SO_4$ to the $ZnCl_2$ fertilizer band may partially explain the higher Zn concentrations obtained in the noncalcareous soil. However, pH in the Stockton soil changed only slightly when $(NH_4)_2SO_4$ was added. This suggests that factors other than just the pH may have been involved. It is interesting to note that addition of $(NH_4)_2SO_4$ to the $ZnCl_2$ fertilizer band in the calcareous soil resulted in a slightly higher pH compared to $ZnCl_2$ applied alone, yet Zn concentration in soil solution was higher with $(NH_4)_2SO_4$ than without. The increases in solubility are likely a result of increased ionic

Table 2. Effect of various N and P fertilizers on total water soluble Zn (mg/column). Stockton FSL.

N or P Fertilizer	Zn Carrier	
	$ZnCl_2$	ZnEDTA
None	0.85	39
$(NH_4)_2SO_4$	4.31	28
Urea	0.27	24
MAP	0.40	22

Table 3. Effect of various N and P fertilizers on total water soluble Zn (mg/column). Almasippi LFS.

N or P Fertilizer	Zn Carrier	
	$ZnCl_2$	ZnEDTA
None	0.04	37
$(NH_4)_2SO_4$	0.28	41
Urea	0.14	42
MAP	0.01	45

strength on the solubility of the precipitates formed and the complexation of Zn with NH_3. Zinc forms tetrahedral and octahedral complexes with NH_3 (Cotton and Wilkinson 1962).

Although there was a large decrease in pH due to addition of MAP to the $ZnCl_2$ fertilizer band, low Zn concentrations in soil solution were obtained when MAP was included. The low Zn concentrations are probably due to the formation of $ZnNH_4PO_4$ which was reported to be the reaction product formed when MAP was applied with an inorganic Zn fertilizer (Kalbasi et al. 1978). The $ZnNH_4PO_4$ was found to be less soluble than $Zn(OH)_2$ or $ZnCO_3$ at pH's normally encountered in neutral and calcareous soils.

Addition of urea in the $ZnCl_2$ fertilizer bands resulted in an increase in pH for both soils. The pH increased by about 3 units in the noncalcareous soil and about 1 unit in the calcareous soil (Fig. 1 and 2). The solubility of Zn in the noncalcareous soil decreased when urea was added to the $ZnCl_2$ fertilizer band. If Zn concentration in soil solution was controlled by the solubility of $Zn(OH)_2$ one would expect the high pH to decrease Zn solubility. In this instance the very large change in pH (3 units) may have countered the effects of ionic strength and complex formation between Zn and NH_3 on solubility. However, solubility of Zn in the calcareous soil was greater with urea and $ZnCl_2$

than with $ZnCl_2$ alone despite increases in pH. In this instance complex formation between NH_3 and Zn and increase in ionic strength probably more than offset the decrease in solubility as a result of the pH change of about 1 unit.

Solubility of Zn in the ZnEDTA Fertilizer Band

Application of the various N and P fertilizers to the ZnEDTA fertilizer band resulted in a similar trend in pH as that obtained with $ZnCl_2$ (Fig. 1,2,5 and 6). Addition of MAP to the fertilizer band resulted in the lowest pH near the site of application, whereas addition of urea resulted in the highest pH. As expected, application of ZnEDTA alone did not have as much influence on the pH near the fertilizer band as did $ZnCl_2$, particularly when it was applied to the calcareous soil.

Solubility of Zn in the ZnEDTA fertilizer band was remarkably high in both soils when compared to the solubility of Zn in the $ZnCl_2$ fertilizer band (Table 2 and 3). It is also evident from the results that addition of the various N and P fertilizers had a significant effect on the solubility of Zn in the ZnEDTA fertilizer band. The effects varied considerably between the two soils used. Solubility of Zn in the ZnEDTA fertilizer band was similar for the two soils with ZnEDTA alone. However, when N or P fertilizers were included in the fertilizer band the solubility of Zn in the noncalcareous soil was approximately 32 to 51 percent lower than the solubilities obtained in the calcareous soil.

Zinc solubility increased for the calcareous soil whereas Zn solubility decreased in the noncalcareous soil when N or P fertilizers were added. Addition of MAP to ZnEDTA for the noncalcareous soil resulted in the lowest level of water soluble Zn in the fertilizer band, while the same P fertilizer was most effective in enhancing Zn solubility when applied to the ZnEDTA fertilizer band for the calcareous soil. The decrease in solubility in the noncalcareous soil may be attributed to the effect of the MAP on pH. The low pH (6.2) resulting from addition of MAP may have decreased the stability of ZnEDTA complex. Norvell and Lindsay (1969) reported that when Fe^{+++}, Ca^{++}, Mg^{++} and H^{+} were competing metal ions in soil solution, ZnEDTA was most stable at pHs of about 6.5 to 7.5. Some of the ionic Zn from the breakdown of the ZnEDTA may have formed the relatively insoluble reaction product $ZnNH_4PO_4$.

Addition of $(NH_4)_2SO_4$ lowered the pH to about 6.5 in the noncalcareous soil, and thereofre may have also decreased the stability of the ZnEDTA complex. The resulting ionic Zn would therefore react with the soil decreasing its solubility.

Urea in contrast to the other fertilizer salts increased pH in the ZnEDTA fertilizer band to about 9.0. The very high pH may have resulted in Ca^{++} and Mg^{++} displacing Zn from the ZnEDTA complex. Lindsay (1979) showed that ZnEDTA decreases in stability at high pHs in the presence of competing metal ions such as Ca^{++} and Mg^{++}.

Application of N and P fertilizer salts to ZnEDTA fertilizer band slightly increased the solubility of Zn in the calcareous soil. The increase in solubility due to addition of $(NH_4)_2SO_4$ and MAP are probably due to a more favourable pH for stability of ZnEDTA (i.e. pH

of 7.5-8.0) than with ZnEDTA alone (pH 8.5). The reason for the increase in solubility with addition of urea is not clear. The pH of the fertilizer band was about 9.0 compared to a pH of about 8.5 with ZnEDTA alone and therefore ZnEDTA should have been less stable with urea than without urea. Perhaps the small difference obtained is due to experimental error.

Movement of Zn in the $ZnCl_2$ Fertilizer Band

Zinc movement from the $ZnCl_2$ fertilizer band was extremely small whether the $ZnCl_2$ was applied alone or in combination with any of the N or P fertilizers (Fig. 3 and 4). The results suggest that there is a very strong interaction between the soil and the applied Zn. Although the extent of movement in both soils was generally limited (1 to 1.5 cm) it appears the extent of movement where Zn concentrations in the fertilizer band were relatively high was greater than in instances in which Zn concentrations were low. This suggests that if the solubility of Zn in the $ZnCl_2$ fertilizer band can be enhanced then a greater movement of Zn from the fertilizer band can be achieved. In this study, $(NH_4)_2SO_4$ was most effective in enhancing Zn solubility and hence the movement of Zn from the $ZnCl_2$ fertilizer band, particularly in the noncalcareous soil.

Movement of Zn in the ZnEDTA Fertilizer Band

Zinc movement from the ZnEDTA fertilizer band was considerably greater than Zn movement from the $ZnCl_2$ fertilizer band (Fig. 3, 4, 7 and 8). Generally extent of movement increased with increase in solubility of Zn in the fertilizer band. It is evident for example from Fig. 7 that the greatest movement in the calcareous soil was obtained when MAP was included in the fertilizer band. Addition of MAP resulted in the highest solubility of Zn in the ZnEDTA fertilizer band. Similarly, in the case of the noncalcareous soil, the greatest movement resulted where either ZnEDTA was applied alone or in combination with $(NH_4)_2SO_4$. As shown before, the solubility of Zn in the ZnEDTA fertilizer band was greatest in these two treatments.

Summary and Conclusions

Studies conducted on a noncalcareous Stockton FSL (pH 7.2) and a calcareous Almasippi LFS (pH 8.4) using sectioned soil columns showed that solubility of Zn in both soils was significantly greater in the ZnEDTA fertilizer band than in the $ZnCl_2$ fertilizer band.

Addition of $(NH_4)_2SO_4$ to the $ZnCl_2$ fertilizer band resulted in a five fold increase in the solubility of Zn in the fertilizer band for the Stockton soil and seven fold increase in Zn solubility for the Almasippi soil when compared to $ZnCl_2$ applied alone. Application of urea to the $ZnCl_2$ fertilizer band decreased Zn solubility in the noncalcareous soil but increased solubility in the calcareous soil. Addition of MAP to the $ZnCl_2$ band decreased solubility of Zn in the fertilizer band for both soils.

When ZnEDTA was applied alone the solubility of Zn in the fertilizer band was similar for both soils. However, when the various N and P fertilizers were included the solubility of Zn in the ZnEDTA fertilizer

band for the Stockton soil was about 32 to 51% lower than the solubilities obtained in the Almasippi soil. Addition of MAP in the ZnEDTA fertilizer band resulted in the lowest solubility of Zn in the fertilizer band in the Stockton soil, but was most effective in enhancing Zn solubility in the Almasippi soil.

Zn movement from the $ZnCl_2$ fertilizer band was extremely small (1.0-1.5 cm) for both soils. $(NH_4)_2SO_4$ was most effective in enhancing Zn movement from the $ZnCl_2$ fertilizer band in both soils. Zn moved to distances of 3.5 to 5 cm from the ZnEDTA fertilizer band, and movement was greater for the calcareous than the noncalcareous soil. The greatest movement of Zn from the ZnEDTA fertilizer band was obtained in the calcareous soil treated with ZnEDTA and MAP.

These studies showed that the greater uptake of Zn by plants from ZnEDTA fertilizer bands is probably due at least in part to the greater solubility and movement of Zn from the ZnEDTA fertilizer band. These studies also showed that addition of other fertilizer salts such as $(NH_4)_2SO_4$, urea and MAP can alter the availability of Zn from both ZnEDTA and $ZnCl_2$ fertilizer bands due to their effect on solubility and movement of Zn from the fertilizer bands.

References

1. Cotton, F.A. and W. Wilkinson (1962). Advanced Inorganic Chemistry, pp.480.

2. Hedayat, M.M. (1978). Effect of Zn Rate and Method of Placement on Yield and Zn Utilization of Blackbeans (Phasealus Vulgaris Var Black Turtle) and Fababeans (Vicia faba L. Var Minor). M.Sc. Thesis, University of Manitoba.

3. Kalbasi, M., G.J. Racz and L.A. Loewen Rudgers (1978). Reaction Products and Solubility of Applied Zn Compounds in Some Manitoba Soils. Soil Sci. Vol. 125 (1):55-64.

4. Lindsay, W.L. (1979). Chemical Equilibria in Soils, pp.249-251.

5. Norvell, W.A. and W.L. Lindsay (1969). Reactions of EDTA Complexes of Fe, Zn, Mn and Cu with Soils. Soil Sci. Soc. Amer. Proc. Vol. 33:86-91.

Fig 1. Effect of N P and Zn Fertilizer on Soil pH

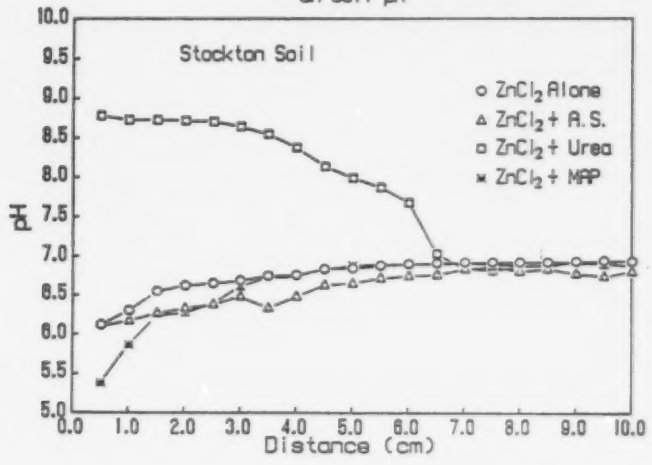


Fig 2. Effect of N P and Zn Fertilizer on Soil pH

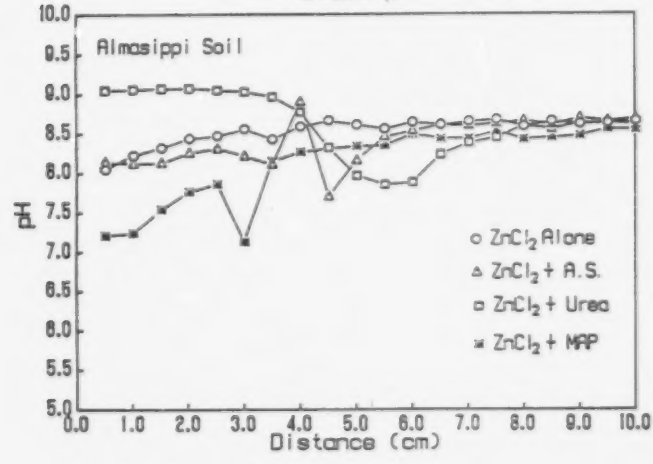


Fig 3. Effect of N P and Zn Fertilizer on Zn Concentration.

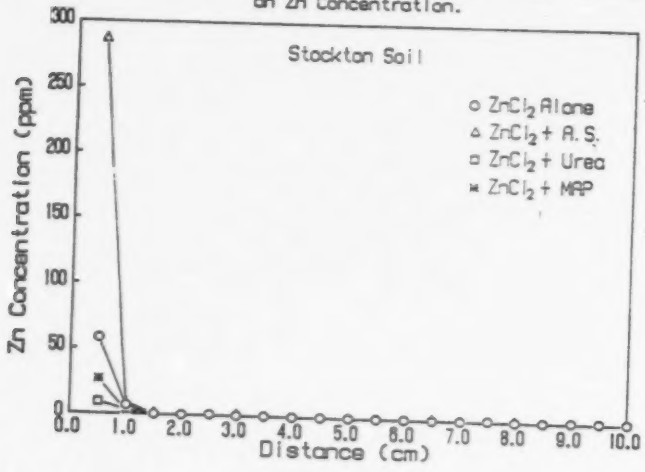


Fig 4. Effect of N P and Zn Fertilizer on Zn Concentration

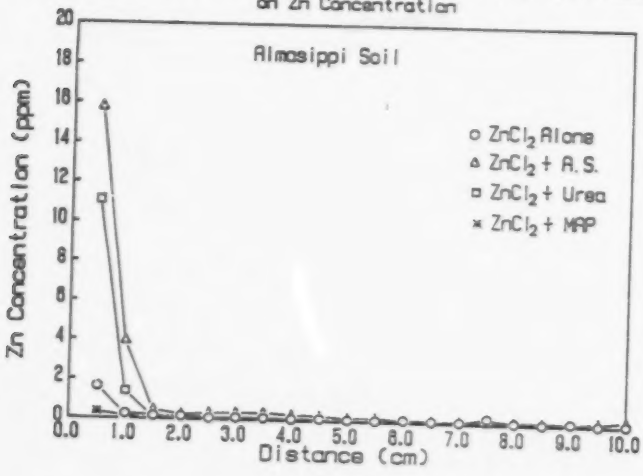


Fig 5. Effect of N P and Zn Fertilizer on Soil pH

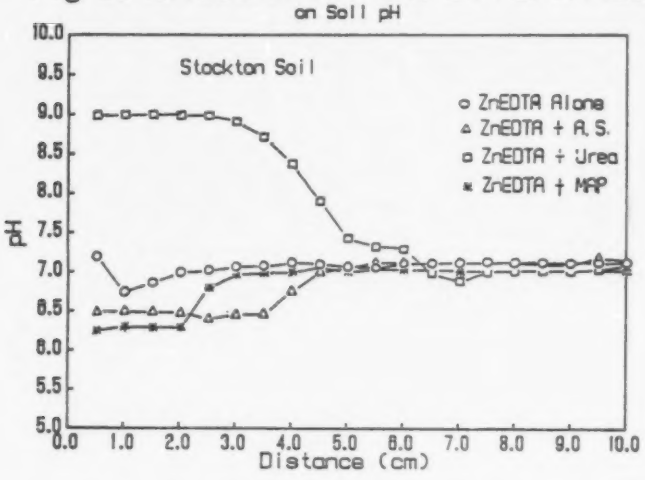


Fig 6. Effect of N P and Zn Fertilizer on Soil pH

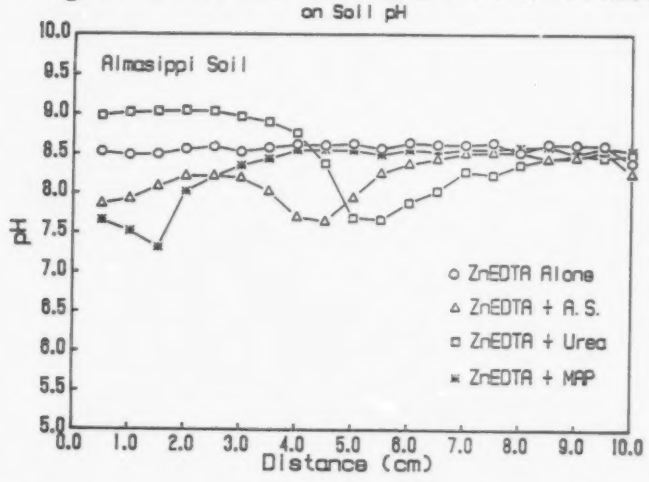


Fig 7. Effect of N P and Zn Fertilizer on Zn Concentration

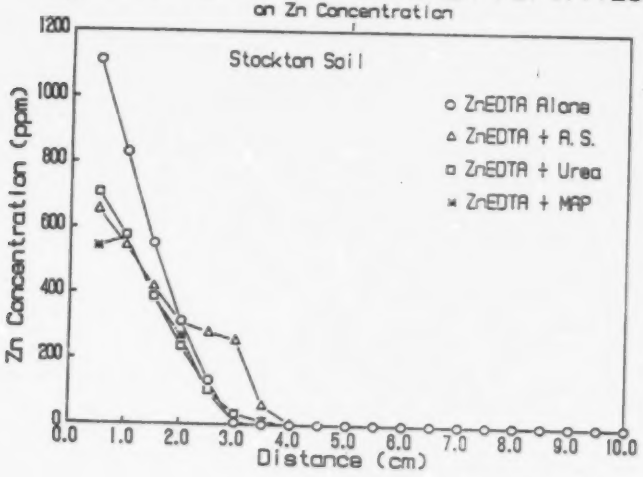
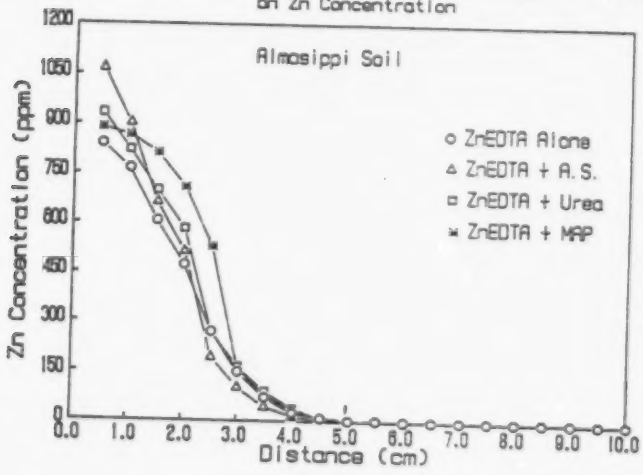


Fig 8. Effect of N P and Zn Fertilizer on Zn Concentration



ABIOTIC INTERACTIONS OF SOIL HUMIC SUBSTANCES WITH PESTICIDES AND RELATED CHEMICALS

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A. INTRODUCTION

Humic substances (HSs) occur in almost every natural water as well as in soils (Choudhry 1984a, b; Stevenson 1982; Wershaw and Pinckney 1978; Schnitzer and Khan 1972) and because of their ubiquity, these macromolecules may interact with pesticides and related chemicals in the environment. The HSs of soil, peat, and water are commonly divided into three major groups, namely, fulvic acids (FAs), humic acids (HAs), and humins based on their solubility in alkali and acid FAs are soluble in both acid and base, whereas humins are insoluble in such media. HAs are soluble in alkaline solutions but insoluble in acid solution.

In this presentation, literature concerning the abiotic interactions of HSs with pesticides as well as some related chemicals is reviewed. Occasionally, examples of interactions between HSs and non-pesticidal environmental pollutants will also be mentioned. The abiotic interactions will be as follows:

- sorptive effects,
- solubilizing effects,
- catalytic effects on hydrolysis,
- photosensitizing and quenching effects,
- photoincorporations.

B. SORPTIVE EFFECTS

Sorption of pesticidal chemicals and other environmental chemicals onto soils and ,their constituents such as clays, humins, humic acids, fulvic acids, etc. is frequently evaluated by the utilization of sorption isotherms. An isotherm represents a relationship between the amount of an environmental chemical (sorbate) sorbed per unit weight of sorbent and the concentration of the chemical (solute, sorbate) in the solution upon achieving equilibrium. Giles and co-workers (1960) divided the isotherms (of organic solutes (adsorbates) adsorbed on solid surfaces) into four main classes, according to the nature of slope of the initial portion of the curve, and thereafter into sub-groups for each class, based on the shapes of the upper parts of the curves. The four main classes (Figure 1) are named the S, L (i.e. Langmuir type), H (high affinity) and C (constant) partition isotherms and the variations in each class are divided into sub-groups. The initial direction of curvature of the S-type curve indicates that adsorption becomes easier as the concentration rises; while, in the case of L-type curves, as more sites in the substrate (adsorbent) are filled it becomes increasingly difficult for a bombarding solute molecule to find a vacant site. The H-type curve is a special case of the L-type curve. The solute has high affinity for the adsorbent, and,

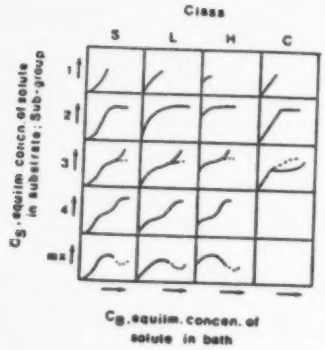


Figure 1. System for classification of adsorption isotherms. (Reproduced from Giles et al., 1960.)

in dilute solutions, is completely adsorbed. The C-type curve is characterized by the constant partition of solute between solution and substrate (adsorbent) (Giles et al. 1960).

In general, three empirical adsorption equations, namely, the Langmuir, Freundlich, and BET equations have been used for the investigtion of adsorption phenomena. Such mathematical equations are described below:

(i) Langmuir adsorption equation

$$\frac{x}{m} = \frac{K_1 K_2 C}{1+K_1 C} \qquad (1)$$

$$\frac{1}{x/m} = \frac{1}{K_2} + \frac{1}{K_1 K_2 C} \qquad (2)$$

(ii) Freundlich adsorption equation

$$\frac{x}{m} = K\, C^{1/n} \qquad (3)$$

$$\log \frac{x}{m} = \log K + \frac{1}{n} \log C \qquad (4)$$

(iii) BET adsorption equation

$$\frac{P}{V(P_o - P)} = \frac{1}{V_m C} + \frac{C-1}{V_m C} \cdot \frac{P}{P_o} \qquad (5)$$

$$C = \frac{b_2 a_1}{b_1 a_2} e^{(E_1 - E_2)/RT} \qquad (6)$$

In equations (1)-(4), x/m is the amount of adsorbate per unit amount of adsorbent, while C is the concentration of solute (adsorbate) at equilibrium. In the Langmuir adsorption equation, K_1 is a constant for the system dependent on temperature, whereas K_2 is the monolayer capacity of the adsorbent.

In the Freundlich adsorption equations, K and n are constants which indicate an indirect measure of the extent of adsorption (i.e., the adsorption capacity) and the nature of the adsorption isotherm, respectively. The exponent 1/n in equation (3) emphasizes that C is raised to the power <1.

In the BET adsorption equation (5), P is the equilibrium pressure at which a volume V of a gas is adsorbed, P_o is the liquefaction or saturation pressure, V_m is the volume of gas adsorbed when the entire surface is covered with a complete monolayer, and C is a constant related to the heat of adsorption, which is defined by equation (6). In equation (6), b_2a_1/b_1a_2 is the ratio of the evaporation-condensation coefficient for the adsorbent layers (often, this ratio has a value near unity), E_1 is the average heat of adsorption of the first adsorbed layer, E_2 is the heat of liquefaction, R is the molar gas constant, and T is absolute temperature (Choudhry 1984a, 1982).

Li and Felbeck (1972a) carried out a detailed study of the mechanism of atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) (for structure, see Section D) adsorption from ethanolic solution onto the ethanol-insoluble fraction of HAs (extracted from muck soil). These investigators plotted 1/(x/m) versus 1/C and obtained straight lines obeying the Langmuir relation (eq. 2) (Figure 2). The K_2 values for

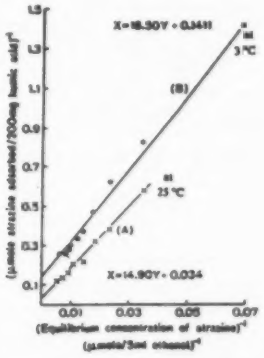


Figure 2. Langmuir (eq. 2) plot for adsorption of atrazine on ethanol-insoluble HAs. (Reproduced from Li and Felbeck, 1972a.)

atrazine adsorption at 25 and 3 °C, obtained from the intercepts of these plots, were 29.41 and 7.07 μmole per 200 mg of HAs, respectively. Since the maximum adsorption is proportional to the adsorption sites available on the HAs, approximately four times as many sites were available at 25°C as at 3°C. The effect of temperature on increasing the number of sites for adsorption could be due to the breaking of the associations of solvent (ethanol) molecules around the reaction sites of HAs and/or atrazine molecules (Li and Felbeck 1972a). The slope of the curves shown in Figure 2 provided the values of $1/K_1K_2$; the values of K_1 thus calculated being 2.3×10^{-3} at 25°C and 7.6×10^{-3} (5 ml/200 mg) at 3°C. Apparently the higher temperature favored the disassociation of HA-atrazine complex, even though the number of reactive sites on HAs increased (Li and Felbeck 1972a).

The equilibnrium and kinetics of adsorption of 2,4-D (2,4-dichlorophenoxyacetic acid) onto soil HAs were reported by Khan (1973). The data obtained from this equilibrium investigation gave reasonably good straight lines by plotting log x/m versus log C (eq. (4)). A typical Freundlich plot for the adsorption of 2,4-D onto HAs at 5°C is given in Figure 3. The values of 1/n (slope) and log K (C = 1 ppm)

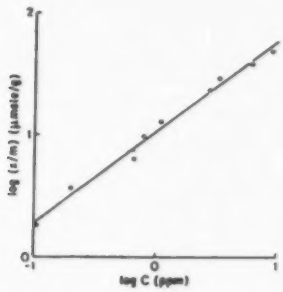


Figure 3. Freundlich (eq. 4) plot for the adsorption of 2,4-D on humic acids at 5°C. (Reproduced from Khan, 1973.)

(intercept) for 2,4-D adsorption on HAs amounted to 0.748 and 1.034 μmole/g, respectively (Khan 1973). In addition, the values of log K and 1/n at 25°C, estimated from similar Freundlich plots using the method of least squares fit were 0.789 and 0.869 μmole/g, respectively (Khan 1973). These observations indicate that the values of 1/n, which describe the intensity of the herbicide adsorption isotherm, decreased with the decrease in temperature. On the other hand, the K value reflecting the adsorptive capacity of the HA surface for 2,4-D increased on raising the temperature of the system.

Chen and Schnitzer (1975) utilized the BET-adsorption equation (5) to analyze their results concerning the sorption of wateer vapor onto soil HAs and FAs of widely differing chemical compositions, particularly with regard to the contents of oxygen-containing functional groups. They used equation (5) after replacing V and V_m (the volume terms) by X

and X_m (the mass (weight) terms). Plots of $P/X\ (P_o-P)$ versus P/P_o for water sorption on HAs and FAs are shown in Figure 4. It is apparent

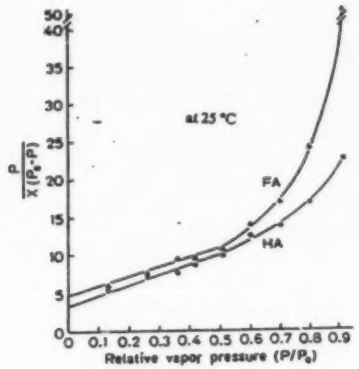


Figure 4. BET (eq. 5) plots of water sorption isotherms onto soil HSs at 25°C. (Reproduced from Chen and Schnitzer, 1976.)

from this figure that both BET plots were linear in the 0-55% relative humidity (RH) (P/P_o x 100) regions for both humic fractions. At higher RH's, slopes of the plots rose sharply and became non-linear, especially in the case of FAs (Figure 4). Chen and Schnitzer (1976) attributed this observation to the substantially greater COOH content of the FAs compared to the HAs. The values of X_m and C were calculated using the slopes and intercepts of the linear sections of these BET plots. The BET parameters, viz., X_m, C, and E_1-E_2 measured in this fashion for the sorption of water onto HAs at 25°C amounted to 58 mg H_2O/g, 3.58, and 0.688 kcal/mole, respectively; while in the case of FAs, values of such parameters were 60 mg H_2O/g, 4.88, and 0.855 kcal/mole, respectively. The BET surface areas (S_{BET}) calculated from these isotherms using 10.6 A^{o2} for the molecular surface area of water amounted to 205.6 and 212.7 m^2/g respectively (Chen and Schnitzer 1976).

Worobey and Webster (1982) studied the binding of ^{14}C-4-chloroaniline with three Manitoba soils (organic, silt loam, and clay loam soils). Figure 5 includes the results of the complexing of this herbicide residue with Manitoba soils. This figure indicates that the percentage of binding of 4-chloroaniline increased with increase in soil organic matter and decrease in clay, particularly at the 500 ppm treatment.

4-chloroaniline

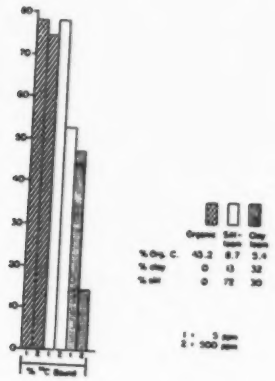
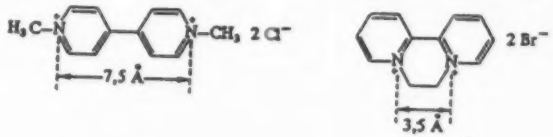


Figure 5. Binding of ^{14}C-4-Chloroaniline with Manitoba soils. The rates of application of the sorbate were 5 ppm (treatment 1) and 500 ppm (treatment 2). (Reproduced from Worobey and Webster, 1982.)

Best and associates (1972) reported on the adsorption of paraquat and



paraquat diquat

diquat in competition and alone onto several organic matter preparations and cation exchange resins. The extent of adsorption of paraquat and diquat as a mixture is documented in Table 1. It is evident from this table that the ratio of paraquat adsorbed to total of diquat + paraquat adsorbed was always larger than 0.50, thereby indicating that the preference was always slightly in favor of paraquat in the case of surfaces of organic matter. However, such ratios for adsorption onto H-, K- or Ba-saturated IR-120 resin were consistently around 0.37 (not included in Table 1) (Best et al. 1972). This observation shows the preferential adsorption of diquat over paraquat by the resins. According to Best and co-workers (1972), the similar adsorption of paraquat and diquat when in competition may be a result of the flexibility (coiling and uncoiling) of the polymeric structure of organic matter in contrast to the rigid structure of layer-silicate minerals, i.e., resins.

Table 1. The adsorption of paraquat and diquat in competition on organic matter. Chemical added: 80 meq/100 g of the organic matter preparation. (Reproduced from Best et al., 1972).

Adsorbent	Chemical adsorbed			Ratio[a] P/D+P	pH at Equilibrium
	Paraquat	Diquat	Total		
(Untreated)[b] Histosol	28.4	27.3	55.7	0.51	4.8
HF:HCl Washed histosol	27.3	22.4	49.7	0.55	3.4
Humic fraction	40.8	35.8	76.6	0.53	3.5
Humin fraction	42.1	36.1	78.2	0.54	6.0
Aldrich Commercial Humic acid	44.1	43.1	87.2	0.51	5.3

[a]Ratio of paraquat (P) and diquat (D) adsorbed.

[b]Obtained near Pentega, North Carolina, and sieved to a particle size of 210 μ or less after air drying.

In 1982, Roemelt and Seitz studied the fluorescence polarization of perylene-fulvic acid binding. Fluorescence polarization is a particularly attractive method for this type of investigation because it can distinguish between free and bound organic substances without a separation. In brief, the fluorophore, namely, perylene (a member of PAH (polycylic aromatic hydrocarbons) family), was excited with polarized light. Fluorescence intensities were measured in the planes parallel ($I_{\parallel}$) and perpendicular ($I_{\perp}$) to the plane of the excitation radiation. The polarization (P) was then calculated from these values using equation (7) (Roemelt and Seitz 1982):

$$P = \frac{I_{\parallel} - I_{\perp}}{I_{\parallel} + I_{\perp}} \qquad (7)$$

Figure 6 shows the polarization of perylene fluorescence as a function of added soil FAs (number average molecular weight being 990) at pH 2 in 75% glycerol (Roemelt and Seitz 1982). It is clear from this figure that the value of P increases with added fulvic acids as expected if

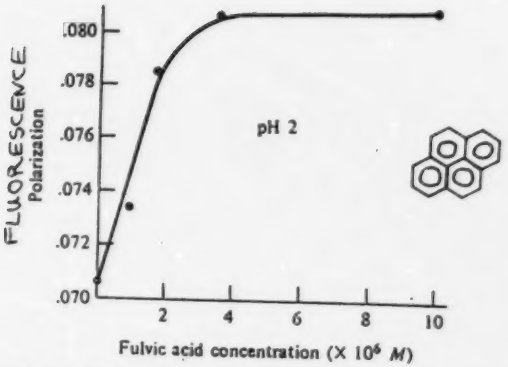


Figure 6. Perylene polarization as a function of added soil fulvic acids in 75% glycerol (4.9×10^{-7} M perylene). (Reproduced from Roemelt and Seitz, 1982.)

perylene binds to a larger molecule. The fact that polarization is constant at fulvic levels above 3×10^{-6}M indicates that the perylene binding onto FAs was complete at this point (see Figure 6). For the determination of equilibrium constants, i.e., binding constant (K_b), Roemelt and Seitz (1982) utilized the following relationship (eq. 8):

$$K_b = \frac{[\text{pery-SFA}]}{[\text{pery}][\text{SFA}]} = \frac{(P-P_f)}{(P_b-P)\left[C_{SFA}-\frac{(P-P_f)}{(P_b-P_f)}C_{pery}\right]} \qquad (8)$$

where C_{SFA} and C_{pery} are total concentrations of soil fulvic acids and perylene, respectively; P_f and P_b are the polarization for free and bound fluorophor, respectively; and P is the observed polarization. The value of K_b for perylene-fulvic acid in 75% glycerol from the point where $P-P_f = P_b-P$ amounted to 1.2×10^6 L/Mol (Roemelt and Seitz 1982).

It is interesting to mention that Gauthier and cc-workers (1986) recently described the fluorescence quenching method for determining equilibrium constants for PAHs binding to dissolved humic substances. This technique is based upon the fact that the intensity of fluorescence is proportionately decreased on adding HAs or FAs. Briefly, the association of a PAH (polyclic aromatic hydrocarbon) with humic substances (Hu) may be represented by the equations (9) and (10) (Gauthier et al. 1986):

$$\text{PAH} + \text{Hu} \longleftrightarrow \text{PAH-Hu} \qquad (9)$$

$$K_b = [\text{PAH-Hu}]/([\text{PAH}][\text{Hu}]) \qquad (10)$$

where PAH-Hu is humic-associated PAH and K_b is the association (i.e. binding) constant. The mass balance on the PAH is described by

equation (11):

$$C_{pah} = [PAH] + [PAH\text{-}Hu] \quad (11)$$

where C_{pah} is the formal or total concentration of PAH. Eq. (10) and (11) provide the following relationship (eq. 12):

$$C_{pah}/[PAH] = 1 + K_b[Hu] \quad (12)$$

If we assume that the fluorescence intensity is proportional to the concentration of free PAH in solution, i.e. [PAH], then

$$F_o/F = 1 + K_b[Hu] \quad (13)$$

where F_o and F are the fluorescence intensities in the absence and presence of humic material, respectively. Equation (13) is in the form of the well-known Stern-Volmer equation frequently utilized in the field of photochemistry. For instance, a Stern-Volmer plot for the association of phenanthrene (a PAH member) with soil FAs obtained using eq. (13) is shown in Figure 7. The value of K_{oc} secured from the

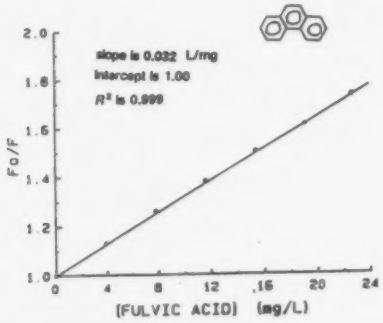


Figure 7. Stern-Volmer (eq. 13) plot for interaction of phenanthrene with fulvic acid. (Reproduced from Gauthier et al., 1986.)

Stern-Volmer plots (Figure 7) for the fluorescence quenching of phenanthrene by the podzolic soil FAs (New Hampshire, U.S.A.) dissolved in water was 7.7×10^4 mL/g, where K_{oc} is the binding constant (K_b) of the pollutant normalized to the organic carbon content (OC) of the sorbing material, i.e., $K_{oc} = K_b/OC$ (Gauthier et al. 1986).

Recently, Gamble and his co-workers (1985a) described theoretical comparison of three ultrafiltration methods, namely continuous flow wash out, continuous flow wash in, and batch dilution curve methods for the measurements of solution phase complexing of atrazine by soil FAs. Furthermore, Gamble et al. (1986b) demonstrated experimentally that the latter method could be used for three purposes. The first purpose was to make direct diagnostic checks for ultrafiltration membrane interferences and other experimental errors. The other two purposes were to investigate the theory of methods for determining complexing

capacity and complexing equiliberium and then to demonstrate them with experimental data (Gamble et al. 1986b).

C. SOLUBILIZING EFFECTS

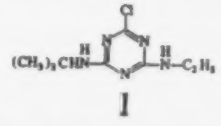
The solubilizing effects of the HSs on pesticides and other environmental chemicals can play a significant role for the dispersion, mobility, and transport of these compounds in aquatic environments. However, only few studies have so far been reported.

Sodium humate has been demonstrated to lower the surface tension of water considerably (Visser 1964), which indicates that these macromolecules can act as a surfactant and thus are capable of solubilizing otherwise insoluble environmental organic chemicals. Wershaw and associates (1969) found that 0.5% Na-salt solution of HAs increased DDT (2,2-bis(p-chlorophenyl)-1,1,1-trichloroethane) solubility by 20-fold. Ballard (1971) noticed that DDT in forest soils was solubilized by HAs when the soils were fertilized with urea; the urea appeared to disperse the HAs. Likewise, Boehm and Quinn (1973) reported that removal of the dissolved organic matter from the natural samples by activated charcoal and by the ultraviolet light oxidation in the presence of H_2O_2 resulted in a 50-99% decrease in the amounts of n-alkane and pristane solubilized. Moreover, Matsuda and Schnitzer (1971) described that dialkyl phthalates are adsorbed onto surfaces of soil FAs to form stable, water-soluble complexes.

Recently, Webster and his co-workers (1986) determined the solubility of three polychlorinated dibenzo-p-dioxins (PCDDs), namely 1,2,3,7-tetrachlorodibenzo-p-dioxin (1,2,3,7-T_4CDD), 1,2,3,4,7-P_5CDD, and 1,2,3,4,7,8-T_6CDD in pure water using a glass bead generator column technique as well as enhanced solubilities of these environmental contaminants in the presence of several dissolved HSs such as HAs and FAs at 20, 30, and 40°C.

D. CATALYTIC EFFECTS ON HYDROLYSIS

Humic substances can play an important role in producing chemical changes via hydrolysis in a variety of environmental chemicals present in water systems. Many researchers have proposed that hydrolysis of the chloro-s-triazines proceeds more rapidly in soil with higher organic matter content (see references cited in Choudhry (1984a) and Gamble and Khan (1988)). The effects of hydrogen ion, buffer-ion (acetate) and humic acids on the hydrolysis of atrazine (1) in aqueous



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solutions have been investigated by Li and Felbeck (1972b). Under such conditions, the hydrolysis of the herbicide 1 followed first-order kinetics. Apparently the hydrolysis measured in these studies could be represented as follows:

$$\text{Atrazine} + H_2O \xrightarrow{\text{catalyst}} \text{Hydroxyatrazine} + H^+ + Cl^-.$$

Obeying the law of mass action, the rate should be dependent on the concentration of two reactants, eq. 14:

$$-\frac{dC_s}{dt} = k\, C_s\, C_{wa} \qquad (14)$$

where C_s is the residual concentration of the substrate 1 (μmole/L) at time t, C_{wa} is the concentration of water and k is rate constant. As the amount of H_2O is in large excess and the amount of water consumed in the course of the reaction is negligible, its concentration may be regarded as constant. The rate equation (14) then is transformed into eq. 15:

$$-\frac{dC_s}{dt} = k_{ob}\, C_s \qquad (15)$$

where k_{ob}, observed rate constant, is equal to kC_{wa}. Li and Felbeck (1972b) plotted the atrazine hydrolysis data according to the eq. (15) (e.g. Figure 8). It is apparent from Figure 8 that, as the amount of

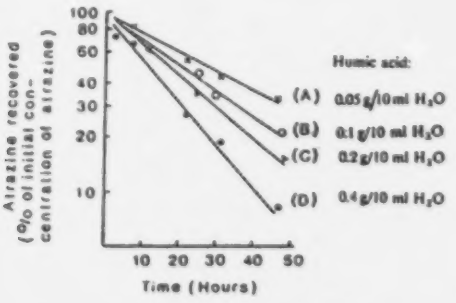


Figure 8. First-order kinetic treatment of hydrolysis of atrazine in the presence of humic acid from a muck soil at pH 4 and 40°C. Initial concentration of atrazine is approximately 60 μmole/L. (Reproduced from Li and Felbeck, 1972b.)

HAs increases, the rate of hydrolysis of atrazine (1) also increases. The hydrolysis rate constant (k_{ob}) and half-lines ($t_{\frac{1}{2}}$) of the compound 1 at various conditions calculated performing first-order kinetic treatment are included in Table 2. This table reveals that in the presence of 0.2 gm of HAs, the herbicide atrazine hydrolyzed about 70 times at 40°C, 140 times at 25°C, and 120 times at 12°C faster compared to the hydrolytic reaction in hydrogen ion solution (pH 4). Moreover, Li and Felbeck (1972b) concluded that both HAs and acetate buffer-ion reduced the energy barrier (Arrhenius activation energy) for the hydrolysis of atrazine.

Table 2. Hydrolysis rate constants (k_{ob}) and half lives ($t_{½}$) of atrazine[a] at different temperatures and conditions. (Reproduced from Li and Felbeck, 1972b).

Catalyst	40°C		25°C		12°C	
	k_{ob} (day^{-1})	$t_{½}$ (day)	k_{ob} (day^{-1})	$t_{½}$ (day)	k_{ob} (day^{-1})	$t_{½}$ (day)
0.2g of humic acid	9.90×10^{-1}	0.70	4.01×10^{-1}	1.73	6.11×10^{-2}	11.34
Acetate buffer (0.08M)	3.76×10^{-2}	18.42	9.70×10^{-3}	71.9	2.29×10^{-3}	302.5
Acetate buffer (0.04M)	2.02×10^{-2}	34.17	5.02×10^{-3}	138	1.04×10^{-3}	661
Hydrogen ion (pH4)	1.42×10^{-2}	48.6	2.84×10^{-3}	244	5.12×10^{-4}	1,352

[a]Initial concentration of atrazine was 60 μmole/l in each run.

Subsequently, in 1978 Khan conducted investigation of the kinetics of atrazine (1) hydrolysis in aqueous fulvic acid solution. Linear curves were secured, when the logarithm of atrazine concentration was plotted against time following eq. (15). Kinetic data for the hydrolysis of atrazine in the presence of dissolved FAs at pH 4.5 and 25°C are as follows:

$k_{ob} = 3.99 \times 10^{-3}$ day^{-1}, $t_{½} = 174$ days for 0.5 mg FA/ml;
$k_{ob} = 12.6 \times 10^{-3}$ day^{-1}, $t_{½} = 55$ days for 1.0 mg FA/ml;
and $k_{ob} = 43.7 \times 10^{-3}$ day^{-1}, $t_{½} = 15.9$ days for 5.0 mg FA/ml

(Khan 1978). It is obvious from this data that a direct relationship existed between the rate of atrazine-hydrolysis and the concentration of FAs. The only product identified by Khan (1978) after hydrolysis in FAs solution was 2-ethylamino-4-hydroxy-6-isopropylamino-1,3,5-triazine (hydroxy atrazine). Recently, Gamble and Khan (1988) have reported the hydrolysis of atrazine in aqueous suspensions of HAs at 25.0°C.

E. PHOTOSENSITIZING AND QUENCHING EFFECTS

Humic substances contain ketonic and quinonoid functional groups and also absorb strongly in the utltraviolet (UV) region (Choudhry 1984a,b, Stevenson 1982, Schnitzer and Khan 1972). These macromolecules thus absorb solar UV light, and can transfer their exitation energy to chemicals such as pesticides present in the environment, thereby acting as photosensitizers. Thus rates of photodegration of pesticides and related chemical can increase. On the other hand, since HSs presumbly contain aromatic polycyclic structures, viz., anthracene, phenanthrene, pyrene, perylene, etc. (Choudhry 1984a, Schnitzer and Khan 1972), these

materials may act as quenchers by accepting the excitational energy of the other chemicals present in the system. Thus HSs can retard the photodegradation of pesticidal chemicals.

Choudhry and associates (1986) described the photodegradation of 1,3,5-trichlorobenzene (1,3,5-Cl_3-Bz) (1.16 mM) in presence and absence of soil FAs in water-acetonitrile (1:1 v/v) using radiations of wavelengths $\geq$ 285 nm. Figure 9 records a time plot for the

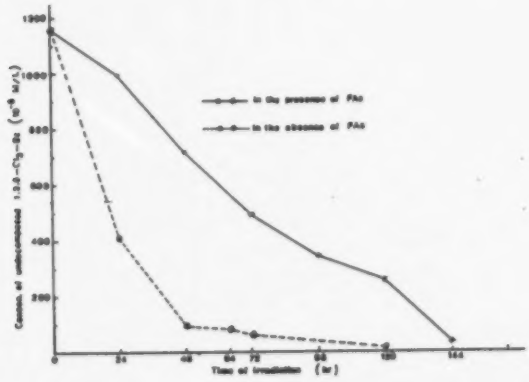


Figure 9. Photolysis of 1,3,5-Cl_3-Bz (1,3,5-trichlorobenzene) with (0.05%, w/v) (—X—X—) and without (--o--o--) the presence of fulvic acids. (Reproduced from Choudhry et al., 1986.)

undecomposed starting 1,3,5-trichlorobenzene for both sorts of solutions. This figure clearly reveals that the photodegradation of the pollutant trichlorobenzene is slower in the presence of FAs. For example, after 24 h exposure to UV light, the percentage disappearance of the starting chlorobenzene without the presence of FAs was 64%, while in the presence of FAs, 14% of the starting material disappeared. The products arising from the photolysis of 1,3,5-Cl_3-Bz were similar regardless of the presence or absence of FAs (Choudhry et al 1986). It should be mentioned that polychlorobenzenes and several other chlorinated aromatic pollutants have been reported to be present in flue gas and fly ash emitted from municipal and industrial incinerators located in Canada, USA, The Netherlands and Japan (Choudhry and Hutzinger 1983).

Khan and Schnitzer (1978) irradiated 1.5×10^{-4} M aqueous solution of atrazine (1) containing 0.01% FAs at pH 3.5, 7.0, and 11.0. Photolysis half-lives of triazine 1 dissolved in water in the absence and presence of FAs are recorded in Table 3. It is evident that the solution phase phototransformation of the herbicide 1 was slower in the presence of FAs compared to that in the absence of these macromolecules (see Table 3). Similarly, half-lives were greatest at low pH and tended to decrease with increase in pH of both types of solutions. This

Table 3. Influence of FA on the photodecomposition of atrazine (1) in aqueous solution. The samples were photolyzed with radiation of 253.7 nm wavelength[a]. (Reproduced from Khan and Schnitzer, 1978.)

pH	Half-lives of aqueous atrazine (1.5×10^{-4} M) solution	
	Without FA's (min)	With 0.01% FA's (min)
3.5	35.0	94.4
7.0	31.6	92.8
11.0	25.7	81.3

[a]Light source was Pen Ray-Lamp which emitted 253.7 nm line comprising 92% of the total radiation.

photoreaction followed first-order kinetics with respect to the herbicide concentration (Khan and Schnitzer 1978). The photoproduct of compound 1 in water following 3 h of UV irradiation was 2-hydroxy-4-ethylamino-6-isopropylamino-s-triazine (hydroxyatrazine). However, when an aqueous solution of atrazine in the presence of 0.01% FA was irradiated until the optical density at 465 nm was <0.01, four photoproducts, namely;

2-hydroxy-4-ethylamino-6-isopropylamino-s-triazine,
2-hydroxy-4-amino-6-isopropylamino-s-triazine,
2-hydroxy-4-ethylamino-6-amino-s-triazine, and
2-hydroxy-4,6-diamino-s-triazine

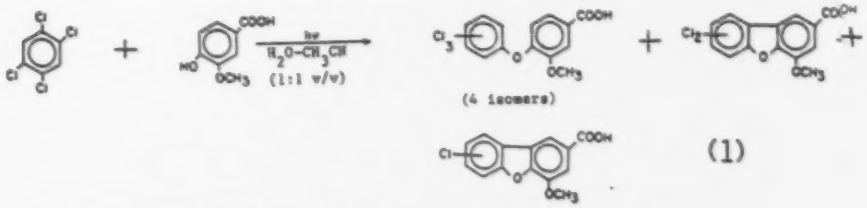
were identified. The products identified after irradiation were similar regardless of pH (Khan and Schnitzer 1978).

Photoreactions of p-cresol, benz(a)anthracene, benzo(a)pyrene, quinoline, benzo(f)quinoline, 9H-carbazole, 7H-dibenzo(c,g)carbazole, benzo(b)thiophene, dibenzothiophene, and methyl parathion have also been reported in the absence and presence of HAs in aqueous solutions utilizing cosolvents such as acetonitrile and methanol in some samples (references cited in Choudhry 1984). The presence of HAs resulted in acceleration (i e. sensitizing) of the photodecomposition of p-cresol by factors of 2 to 12 over those in pure water. In general, the HAs retarded the photolyses of the rest of the substrates.

F. PHOTOINCORPORATIONS

To date, no attention has been paid to the likely photoincorporations of pesticidal chemical and other environmental pollutants into humic macromolecules. However, we have recently reported the photoincorporating reactions of polychlorobenzenes with several humic model monomers (Choudhry et al. 1987, 1986, 1983).

Recently, Choudhry and associates (1987, 1986) reported the photoincorporations of tri-(1,3,5-isomer), tetra-, penta-, and hexachlorobenzenes with humic model monomers, viz., benzaldehyde, benzoic acid, vanillin, vanillic acid, syringaldehyde, and syringic acid as aqueous solutions utilizing acetonitrile as cosolvent at $\geq$ 290 nm. All the investigated chlorobenzenes except hexachlorobenzene provided photoproducts in yields <1% formed apparently by the reaction of the intermediate polychlorophenyl radicals with individual humic monomers. In the presence of benzoic acid and benzaldehyde, chlorophenylation of the humic monomers occurred. In the case of monomers having phenolic OH group, substituted polychlorodiphenyl ether and dibenzofurans were also formed (e.g. Reaction 1) (Choudhry et al. 1987, 1985):



(1)

Likewise, Choudhry et al. (1983) observed the formation of polychlorodibenzopfurans (PCDFs), when polychlorobenzenes containing 4, 5, and 6 chlorine substituents in aqueous acetonitrile were photolyzed in the presence of phenol at $\lambda \geq 290$ nm. Under these conditions, chlorobenzenes produced PCDFs with 2 Cl contents less than those of starting materials. Choudhry and associates (1983) concluded that these photoincorporating products PCDFs were yielded through the intermediacy of appropriate polychlorodiphenyl ethers, which underwent secondary photochemical reactions.

G. CONCLUDING REMARKS

In the context of sustained agricultural production, the results of the above reviewed literature have potentially significant implications and applications. For instance:

(a) Sorption of pesticides onto the surfaces of soil HSs (in the free form as well as bound to soil minerals) may decrease the efficacy of soil-applied pesticides.

(b) On the other hand, the enhancement of solubility of pesticides will increase the chances of the availability of pesticides for the grown crops, i.e., pesticide efficacy will increase.

(c) Likewise, the hydrolysis of pesticides caused by catalytic actions of soil HSs will again result in decreasing pesticide efficacy; however, this process will decrease the pollution of aquatic systems.

(d) Furthermore, the photoquenching effects of HSs will lead to minimizing the sunlight photolytic losses of pesticides.

(e) Finally, the fluorescence quenching Stern-Volmer plots can be utilized for the determination of the binding constants of metallic both micro- and macro nutrients with soil HSs.

H. REFERENCES

Ballard, T.M., Soil Sci. Am. Proc. 35, 145 (1971).

Best, J.A., J.B. Weber and S.B. Weed, Soil Sci. 144, 444 (1972).

Boehm, P.D. and J.G. Quinn, Geochim. Cosmochim. Acta 37, 2459 (1973).

Chen, Y. and M. Schnitzer, Can. J. Soil Sci. 56, 521 (1976).

Choudhry, G.G., "Humic Substances: Structural, Photophysical, Photochemical and Free Radical Aspects and Interactions with Environmental Chemicals". Gordon and Breach Sci. Publish., New York, pp. 1-185 (1984a), and references cited therein.

Choudhry, G.G., Residue Rev. 92, 59 (1984b).

Choudhry, G.G., and O Hutzinger, "Mechanistic Aspects of the Thermal Formation of Halogenated Organic Compounds Including Polychlorinated Dibenzo-p-dioxins". Gordon and Breach Sci. Publish., New York, pp. 1-195 (1983).

Choudhry, G.G., J.A. van den Broecke and O. Hutzinger, Chemosphere 12, 487 (1983).

Choudhry, G.G., G.R.B. Webster and O. Hutzinger, Toxicol. Environ. Chem. 13, 27 (1986).

Choudhry, G.G., J.A. van den Broecke, G.R.B. Webster and O. Hutzinger, Environ. Toxicol. Chem. 5, 625 (1986).

Choudhry, G.G., J.A. van den Broecke, G R.B. Webster and O. Hutzinger, Chemosphere 16, 495 (1987).

Gamble, D.S. and S.U. Khan, "Atrazine hydrolysis in aqueous suspension of humic acid at 25.5°C". Submitted for publication, 1988.

Gamble, D.S., M.I. Haniff and R.H. Zienius, Anal. Chem. 58, 727 (1986a).

Gamble, D.S., M.I. Haniff and R.H. Zienius, Anal. Chem. 58, 732 (1986b).

Gauthier, T.D., E.C. Shane, W.F. Guerin, W.R. Seitz and C.L. Grant, Environ. Sci. Technol. 20, 1162 (1986).

Giles, C.H., T.H. MacEwan, S.N. Nakhwa and D.M. Smith, J. Chem. Soc., 3973 (1960).

Khan, S.U., Can. J. Soil Sci. 53, 429 (1973).

Khan, S.U., Pest. Sci. 9, 39 (1978).

Khan, S.U. and M. Schnitzer, J. Environ. Sci. Health B13, 299 (1978).

Li, G.-C. and G.T. Felbeck, Soil Sci. 113, 140 (1972a).

Li, G.-C. and G.T. Felbeck, Soil Sci. 114, 201 (1972b).

Matsuda, K. and M. Schnitzer, Bull. Environ. Contam. Toxicol. 6, 200 (1971).

Roemelt, P.M. and W.R. Seitz, Environ. Sci. Technol. 16, 613 (1982).

Schnitzer, M. and S.U. Khan, "Humic Substances in the Environment". Marcel Dekker, New York, pp. 1-327 (1972).

Stevenson, F.J., "Humus Chemistry: Genesis, Composition, Reactions". John Wiley and Sons, New York, pp. 1-443 (1982).

Visser, S.A., Nature 204, 581 (1964).

Webster, G.R.B., D.H. Muldrew, N.J. Graham, L.P. Sarna and D.C.G. Muir, Chemosphere 15, 1379 (1986).

Wershaw, R.L. and D.J. Pinckney, Science 199, 906 (1978).

Wershaw, R.L., P.J. Burcar and M.C. Goldberg, Environ. Sci. Technol. 3, 271 (1969).

Worobey, B.L. and G.R.B. Webster, J. Agric. Food Chem. 30, 164 (1982).

EFFECTIVENESS OF SEVERAL SULPHUR SOURCES IN ALLEVIATING SULPHUR DEFICIENCY OF CROPS

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INTRODUCTION

Sulphur deficiency has been recognized as a serious limitation to crop production in widespread areas of soil in western Canada. Fertilization strategies to alleviate these deficiencies, however, have not yet been adequately developed, in part because of the numerous and diverse S fertilizers currently on the market. Particular uncertainty exists regarding the effectiveness and agronomic role of elemental S products, which require microbial oxidation to sulphate before they can be absorbed by plants.

The objective of the current study was to compare the effectiveness of selected S fertilizers in the alleviation of S deficiency as measured by yield response, S uptake response, and changes in soil sulphate concentrations. Because elemental S products may conceivably have considerable residual benefits, the experiments were designed to continue over several years. Reported in this manuscript are results from the first two years. Detailed results of the first year of experimentation have been reported by Janzen et al. (1987) and Karamanos et al. (1987) elsewhere.

MATERIALS AND METHODS

Two field experiments were conducted in north-central Alberta on a Transitional Grey Black and a Grey soil, respectively (Table 1).

Table 1. Characteristics of the sites of sulphur experiments

Experiment	Location	Soil type	pH	Sulphates (0-60 cm)
				kg ha^{-1}
A	Wetaskiwin, Alta	Grey Black	5.3	17.2
B	Westerose, Alta	Grey	6.0	15.0

Experiment A. This experiment was initiated in 1986 and employed a split-split plot design with three elemental S sources as main plots, four rates of elemental S (0, 30, 60, and 120 kg S ha^{-1}) as sub-plots and five rates of sulphate (0, 5, 10, 20, and 40 kg S ha^{-1}) as sub-sub-plots. The three commercially available elemental S sources included two 90% elemental S + 10% bentonite products (henceforth, 90% S^{o}(a) and 90% S^{o}(b)) and a finely-divided elemental S suspension (henceforth 95% S^{o}). The sulphate treatments, applied as ammonium sulphate (21-0-0-24 in 1986 and 20-0-0-24 in 1987), were superimposed over every source.

The main plots and sub-subplots were 22.5 m X 24 m and 22.5 m X 6 m in size, respectively. Each sub-plot area was divided into three equal parts (7.5 m X 6 m) to accomondate annual applications of ammonium sulphate over a three year period onto 1.5 m X 6 M sub-sub-plots. All treatment were replicated four times.

The two 90% S^{o} products were broadcast onto the surface of the plots and incorporated into the top 2-4 cm of soil. The 95% S^{o} was suspended in water in accordance with the manufacturer's instructions, sprayed onto the surface of the plot and incorporated into the surface 2-4 cm of soil. Sulphate, as ammonium sulphate, was broadcast by hand and incorporated. The entire plot area received a blanket band application of 50 kg P_2O_5 ha^{-1} as monoammonium phosphate and 64 kg N ha^{-1} anhydrous ammonia in 1986 and 40 kg P_2O_5 ha^{-1}

seed-placed in 1987. As well, additional N (up to 40 kg N ha^{-1}) was applied (as urea in 1986 and as ammonium nitrate in 1987) in both years to compensate for N added in the various ammonium sulphate treatments and equalize N additions in all plots.

Canola (Brassica napus cv. Westar) was seeded on May 29, 1986 at a rate of 11 kg ha^{-1}. Effective weed control was achieved by appropriate herbicidal treatment. On September 22-24, all plant material from a 3-row by 3.04 m portion of each sub-sub-plot was harvested by hand. The material was dried, weighed and threshed for determination of seed yield.

Soil samples from each sub-sub-plot were obtained on June 25 (0-15 and 15-30 cm depths), July 23 (0-15, 15-30, and 30-60 cm depths in block one only), and October 15 and 16 (0-15, 15-30, and 30-60 cm depths). In all cases, 4 cores were taken from every sub-sub-plot and composited. Plant tissue samples were obtained on June 25 and July 23 by harvesting 15 entire plants from every sub-sub-plot and bulking replicates. On May 13, 1987 soil samples were obtained from each sub-plot (0-15, 15-30, and 30-60 cm depths) from the areas where no ammonium sulphate was applied in 1986.

The fertilizer treatments in 1987 were applied on May 27 and the entire plot area was seeded to barley (Hordeum vulgaras cv. Bonanza) at a rate of 87 kg ha^{-1}. Effective weed control was achieved by appropriate herbicidal treatment. On September 8-9, all plant material from a 3-row by 3.04 m portion of each sub-sub-plot (1986 and 1987 sub-sub-plots) was harvested by hand. The material was dried, weighed and threshed for determination of grain yield. Soil samples (0-15, 15-30, and 30-60 cm depths) from all 1986 and 1987 sub-sub-plots were obtained on September 30 and October 1, 1987.

Experiment B. This experiment was initiated in 1987 and employed a split-split plot design with two elemental S sources and ammonium sulphate as main plots, four rates of elemental S or ammonium sulphate (0, 15, 30, and 60 kg S ha^{-1}) as sub-plots and three rates of sulphate (0, 15, and 30 kg S ha^{-1}) as sub-sub-plots. The two commercially available elemental S sources included a 90% elemental S + 10% bentonite product (90% S^{o}(b) of Experiment A) and a finely-divided elemental S (95% S^{o} of Experiment A). The sulphate treatments (both sub- and sub-sub-plot) were applied as ammonium

sulphate (20-0-0-24).

The main plots and sub-subplots were 22.5 m X 24 m and 22.5 m X 6 m in size, respectively. Each sub-plot area was divided into three equal parts (7.5 m X 6 m) to accomodate annual applications of ammonium sulphate over a three year period onto 2.5 m X 6 M sub-sub-plots. All treatments were replicated four times.

The 90% S^{o} product was broadcast onto the surface of the plots. The 95% S^{o} was suspended in water in accordance with the manufacturer's instructions, sprayed onto the surface of the plot and incorporated into the surface 2-4 cm of soil. Sulphate, as ammonium sulphate, was broadcast by hand and incorporated. The entire plot area received a blanket seed-placed application of 40 kg P_2O_5 ha^{-1}. As well, additional N (up to 75 kg N ha^{-1}) was applied as ammonium nitrate to compensate for N added in the various ammonium sulphate treatments and equalize N additions in all plots.

Barley (Hordeum vulgarae cv. Bonanza) was seeded on May 27, 1987, at a rate of 87 kg ha^{-1}. Effective weed control was achieved by appropriate herbicidal treatment. On September 16, all plant material from a 3-row by 3.04 m portion of each sub-sub-plot was harvested by hand. The material was dried, weighed and threshed for determination of grain yield.

Soil samples from each sub-sub-plot were obtained on July 14 (0-15, 15-30, and 30-60 cm depths) and October 1 and 2 (0-15, 15-30, and 30-60 cm depths). In all cases, 3 cores were taken from every sub-sub-plot. Plant tissue samples were obtained on June 15 by harvesting 15 entire plants from every sub-sub-plot.

All soil samples were air-dried, ground to pass through a 2 mm sieve and extracted with 0.01M $CaCl_2$ for determination of sulphate and nitrate concentrations. Plant samples were dried (60 ^{o}C) and ground to <40 mesh in preparation for chemical analysis. The N conentration was determined by sulphuric acid/hydrogen peroxide digestion and subsequent colorimetric analysis, while S concentration was determined by combustion in a Leco S analyzer. All analyses were carried out at Norwest Labs, Edmonton.

All replicated data were subjected to analysis of variance for a split-split-plot design with three main plots, four sub-plots, and five sub-sub-plots for Experiment A and three main plots, four

sub-plots and three sub-sub-plots for Experiment B. Response surfaces were estimated for selected results using the following regression model:

$$Z = c + a_1X + a_2X^2 + a_3Y + a_4Y^2 + a_5XY$$

where Z = predicted value of parameter,

X = rate of main source S (kg S ha^{-1}),

Y = rate of ammonium sulphate in sub-sub-plots (kg S ha^{-1}),

c = intercept, and a_1, a_2, a_3, a_4, and a_5 are regression coefficients.

"Apparent oxidation" of elemental S sources at each sampling interval was estimated from crop uptake and residual soil sulphate data (differences between S treatments and control for 0-30 cm depth).

RESULTS

Yield

Experiment A. Canola seed yield was significantly affected by elemental S source, elemental S rate, sulphate rate, and the interactive effects of sulphate rate and elemental S source (Table 2). In the absence of elemental S application, sulphate application resulted in up to 3-fold increases in the yield, indicating severe S deficiency in treatments receiving no S fertilizer.

The canola yield response to the various elemental S products varied. The 95% S^o produced maximum yield response at the lowest rate of S application (30 kg S ha^{-1}). Neither additional sulphate nor higher rates of 95% S^o application elicited further yield response.

The two bentonite (90% S^o) products were much less effective than 95% S^o in increasing yield. While a yield response to both products was evident (approximately 400 kg ha^{-1} in absence of sulphate application), neither product resulted in maximum seed yield response even at high (120 kg S ha^{-1}) application rate. Thus, supplemental addition of sulphate to treatments receiving 120 kg elemental S ha^{-1} still resulted in significant yield responses.

Barley grain yield was significantly affected by ammonium

Table 2. Effect of several sources and rates of elemental S applied in combinations with various rates of sulphate on seed yield of canola in Experiment A

S^o source	S^o rate	Sulphate rate (kg S ha^{-1})				
		0	5	10	20	40
		kg ha^{-1}				
95%	0	838	1012	1439	1549	1640
	30	1722	1611	1502	1589	1625
	60	1705	1488	1712	1675	1274
	120	1594	1560	1341	1627	1494
90% (a)	0	582	1138	1324	1470	1517
	30	752	1275	1682	1511	1684
	60	736	1212	1292	1305	1564
	120	984	1339	1562	1450	1748
90% (b)	0	672	1520	1533	1544	2060
	30	841	1268	1672	1691	1742
	60	925	1538	1812	1684	1611
	120	1003	1642	1558	1818	1497

The following effects are statistically significant:
source(P=0.002), elemental S rate (P=0.07), sulphate rate (P=0.0001), source X rate (P=0.0001)

sulphate rates applied in 1986, elemental S source and ammonium sulphate rates applied in 1987 (Tables 3 and 4). The magnitude of barley grain yield responses obtained in 1987 was considerably lower compared to those of canola seed obtained in 1986 reflecting the difference in nutritional requirements between the two crops.

The relative canola seed and barley grain yield response to the various elemental S products can be further illustrated by examining the response to sulphate superimposed over these elemental S treatments (Table 5). Theoretically, if the elemental S application adequately corrected S deficiency, then further addition of sulphate would provide no further yield increase. Furthermore, the more effective the elemental S product, the less should be the response to the sulphate fertilizer. Supplemental sulphate application to the various 95% S^o treatments resulted in no further increases in yield, indicating complete correction of S deficiency by elemental S application in the year of application. In contrast, sulphate application elicited very substantial yield increases in the 90% S^o

Table 3. Effect of several sources and rates of elemental S applied in combinations with various rates of sulphate applied in 1986 on grain yield of barley grown in 1987 in Experiment A

S^o source	S^o rate	Sulphate rate (kg S ha^{-1})				
		0	5	10	20	40
	kg ha^{-1}					
95%	0	3242	3488	3421	3471	3786
	30	3751	3816	3514	3723	3682
	60	3724	3618	3698	3744	3817
	120	3822	3877	3860	3915	4060
90% (a)	0	3404	3281	3698	3842	3945
	30	3519	3756	3982	4154	4004
	60	3568	3670	3745	3764	4033
	120	3261	3480	3529	3780	4010
90% (b)	0	3598	3628	3818	3857	4142
	30	3438	3647	3726	4137	3992
	60	3425	3469	3614	3540	3674
	120	3528	3493	3344	3433	4061

The following effects are statistically significant:
sulphate rate (P=0.0001)

treatments in the year of application and significant increases in the subsequent year. Clearly, the S^o+bentonite products, while providing some available S, did not nearly alleviate S deficiency even when applied at very high rates.

Experiment B. Barley grain yields in this experiment were only significantly ($P<0.01$) affected by the rates of supplemental sulphate (Fig. 1). The magnitude of yield increases was again considerably lower than that of canola in Experiment A.

Canola total S uptake

The total S content of the vegetative parts and seed of canola (Fig. 2) showed greater response to S fertilizer than either seed yield (Table 2) or S concentration (Fig. 3). Mean treatment values ranged from as low as 10 kg S ha^{-1} where no S was applied to as high as 40 kg S ha^{-1} where effective S fertilizers were applied. These differences were the result of significant effects of elemental S source (P=0.06), elemental S rate (P=0.001), sulphate rate (P=0.001), and source X elemental S rate interactions (P=0.001).

Table 4. Effect of several sources and rates of elemental S applied in combinations with various rates of sulphate applied in 1987 on grain yield of barley grown in 1987 in Experiment A

S^0 source	S^0 rate	Sulphate rate (kg S ha^{-1})				
		0	5	10	20	40
		kg ha^{-1}				
95%	0	3459	3871	3782	3844	4148
	30	3971	4217	3743	3992	4250
	60	4084	4225	4058	4236	4107
	120	4007	3980	3982	4025	4062
90% (a)	0	3633	3593	3829	3867	4129
	30	3790	3863	3767	3841	4210
	60	3617	3715	3928	4016	4040
	120	3720	3687	3924	3972	4027
90% (b)	0	3592	3744	3895	3920	4156
	30	3635	3759	4067	4029	4060
	60	3728	3691	3876	4050	4055
	120	3859	3785	4029	3932	4043

The following effects are statistically significant:
main source (P=0.05) and sulphate rate (P=0.0001)

Table 5. Canola seed and barley grain response to supplemental application of sulphate at 40 kg ha^{-1} to various elemental S treatments in Experiment A

S^0 source	S^0 rate	Yield increase					
				Barley 1987			
		Canola 1986		1986 applied		1987 applied	
	kg ha^{-1}	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%
95%	30	-97	-6	-68	-2	279	7
	60	-132	-9	93	2	22	0.5
	120	100	6	239	6	54	1
90% (a)	30	932	124	485	14	420	11
	60	828	112	465	13	423	12
	120	764	77	749	23	307	8
90% (b)	30	902	107	554	16	425	12
	60	686	74	249	7	328	9
	120	815	81	533	15	184	5
Control	-	1042	149	544	16	583	16

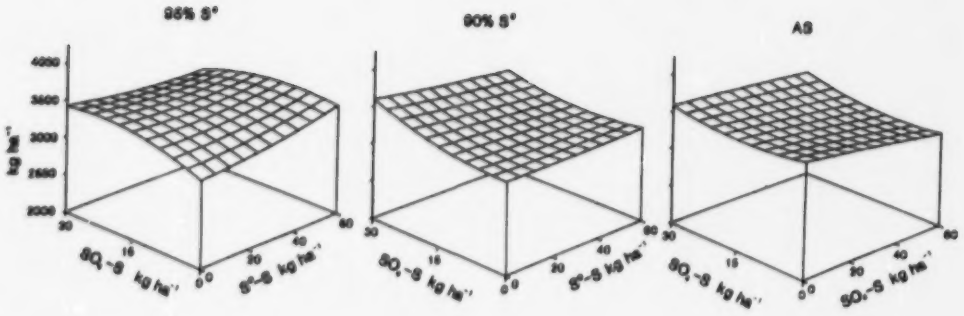

Fig. 1. Effect of elemental and sulphate application on barley yield (kg ha^{-1}) in Experiment 8.

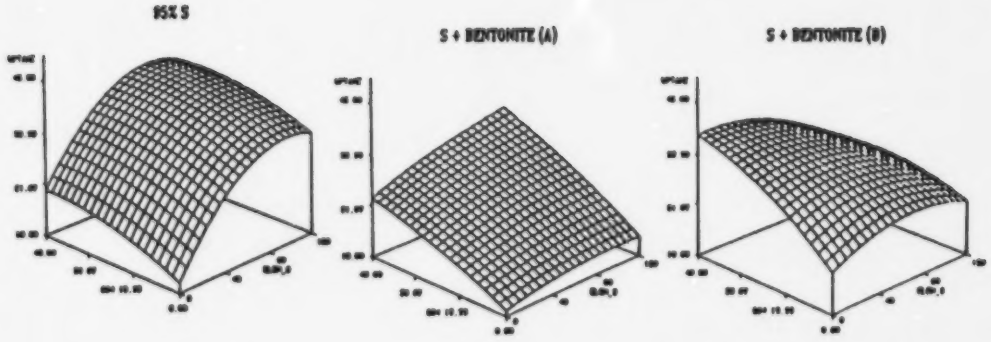

Fig. 2. Effect elemental and sulfate application on S uptake (kg/ha) in canola.

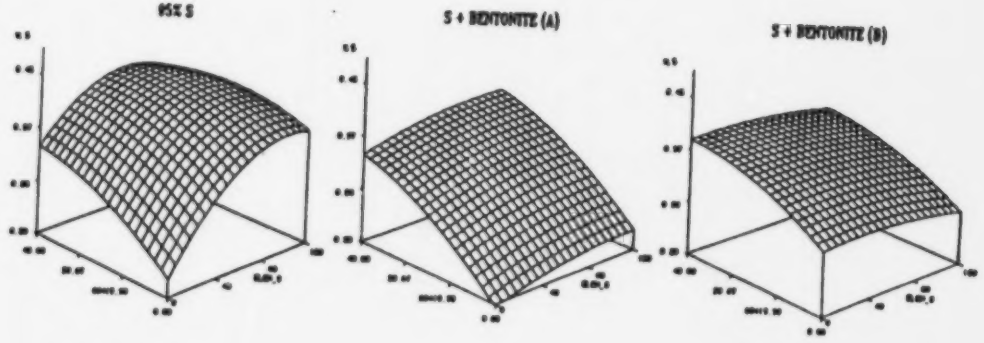

Fig. 3. Effect of elemental S and sulfate application on S concentration (%) in canola seed.

In the 95% S^0 treatments, both sulphate and elemental S application substantially enhanced S uptake (Fig. 2a). Highest uptake was observed when both 95% S^0 and sulphate were applied. The S uptake in the 60 and 120 kg ha^{-1} 95% S^0 treatments receiving no sulphate was higher than uptake when sulphate alone was applied at 40 kg S ha^{-1} rate.

The 90% S^0 products had only marginal effect on total S uptake (Fig. 2b,c). At all rates of elemental S application for these products, supplemental application of sulphate resulted in large increases in total S uptake.

The increase in S uptake resulting from elemental S application can be estimated using the following equation:

$$F = [\sum_{i=1}^{5} (S_i - C_i)]/5$$

where F = crop S uptake derived from fertilizer S^0

S_i = total crop S uptake in sulphate treatment i with S^0

C_i = total crop S uptake in sulphate treatment i without S^0

On the basis of this equation the mean increase in S uptake attributable to elemental S application was 16, 5, and 0 kg S ha^{-1} for the 95% S^0, 90% S^0(a) and 90% S^0(b) products, respectively (Table 6). In the 95% S^0 treatments, the S values increased with increasing elemental S application rate. These values support earlier observations that the 95% S^0 was made readily available over the course of the growing season while the two 90% S^0 products had only limited effectiveness.

Soil sulphate

Experiment A. Concentrations of extractable sulphate measured on June 25, 1986 were not significantly influenced by elemental S source or application rate. The absence of a significant effect suggests that either cumulative oxidation at this time was minimal or that any sulphate which had been produced was utilized by the crop or soil microorganisms. The concentration of soil sulphate in the surface 30 cm increased with increasing rate of sulphate application but did not fully account for amounts of sulphate applied (Table 7). On average, the increases in soil sulphate concentrations accounted for

Table 6. Estimated uptake of elemental S into above-ground plant parts of canola in Experiment A

S^o source	S^o rate kg S ha^{-1}	Uptake*	
		kg ha^{-1}	% of applied
95% S^o	30	9.4	31
	60	18.7	31
	120	19.8	16
90% S^o (a)	30	5.5	18
	60	3.4	6
	120	7.4	6
90% S^o (b)	30	-1.1	-
	60	3.7	6
	120	-3.4	-

The following effects were statistically significant: source (P=0.003), elemental S rate (P=0.04), source X elemental S rate (P=0.007), source X sulphate rate (P=0.08)
* averaged over sulphate treatments

Table 7. Effect of sulphate application rate on levels of extractable sulphate in the surface 30 cm soil layer in Experiment A

Sulphate-S rate kg ha^{-1}	Sulphate S in the 0-30 cm depth		
	kg ha^{-1}	increase	% of applied
0	21.4	-	-
5	23.4	2.0	40
10	29.5	8.2	82
20	30.8	9.4	47
40	39.2	17.8	44

Effect of sulphate application rate significant at P=0.0001. All main and interactive effects involving elemental S source or rate were not significant

approximately half of the sulphate applied. The apparent loss of sulphate can be attributed largely to immobilization into organic S forms and, to a lesser extent, plant uptake.

Measurement of extractable soil sulphate concentrations after crop harvest demonstrated significant effects of elemental S

Table 8. Effects of source and rate of elemental S application on concentration of extractable sulphate remaining after the 1986 canola harvest in Experiment A

S^0 source	Rate	Extractable sulphate				
		0-15 cm	15-30 cm	30-60 cm	0-30 cm	0-60 cm
		kg S ha^{-1}				
95% S^0	0	8	6	9	14	23
	30	12	9	14	21	35
	60	21	13	17	34	51
	120	51	22	31	72	103
90% S^0(a)	0	10	5	7	15	22
	30	9	5	11	14	25
	60	9	5	7	14	21
	120	12	8	9	20	30
90% S^0(b)	0	9	8	12	17	30
	30	13	15	39	28	67
	60	14	14	34	28	63
	120	16	10	36	25	61
		Significance				
Source		ns	ns	ns	ns	ns
S^0 rate		.001	ns	.06	.01	.01
Sulphate rate		.001	.01	ns	.0001	.0001
Source X S^0 rate		.002	ns	ns	.008	.07
Source X sulphate rate		ns	ns	ns	ns	ns
S^0 rate X sulphate rate		ns	.08	ns	.02	ns
Source X sulphate rate X S^0 rate		ns	ns	ns	ns	ns

application (Table 8). Concentrations of sulphate in the 30-60 cm soil layer were subject to considerable variability, presumably because of the presence of relatively sulphate-rich substrate layers at variable depth in the profile.

Experiment B. Concentrations of extractable sulphate measured on July 14, 1987 were significantly influenced by main source, main source rate, and rate of supplemental ammonium sulphate (Table 9). The increases in sulphate concentration reflected effectiveness of main source in supplying sulphates to the barley crop and rates of application. Thus at 60 kg S ha^{-1} of main source application rate, supplemental sulphate rates could be fully accounted for in 95% S^0 and ammonium sulphate treatment but for 90% S^0 only approximately

Table 9. Effects of source and rate of main S source application on concentration of extractable sulphate on July 14, 1987 in Experiment B

S^o source	Rate	Extractable sulphate				
		0-15 cm	15-30 cm	30-60 cm	0-30 cm	0-60 cm
		kg S ha^{-1}				
95% S^o	0	17.0	5.3	5.5	22.3	27.8
	15	22.4	4.6	5.5	27.0	32.5
	30	28.4	4.3	7.6	32.7	40.3
	60	38.4	6.1	8.1	44.5	52.6
90% S^o	0	14.7	5.9	7.3	20.6	27.9
	15	17.2	4.4	4.9	21.6	26.5
	30	19.3	5.5	6.1	24.7	30.8
	60	19.0	5.9	9.2	24.9	34.8
Amm Sulphate	0	17.2	6.2	8.6	23.4	32.0
	15	24.9	4.7	6.7	29.6	36.3
	30	46.4	5.7	7.3	52.1	59.4
	60	51.9	5.9	8.5	57.8	66.3

half of the supplemental sulphate could be accounted for by the increase in soil sulphate levels presumably due to higher use of sulphate by the crop in these treatments.

Estimation of oxidation

A rough estimate of the proportion of elemental S oxidized over a period can be calculated using the following equation:

$$P = \left(\sum_{j=1}^{3} \left(\sum_{i=1}^{5} [(T_{i,j} - T_{i,o})/A_j] \right) \right)/15$$

where P = proportion of S^o applied recovered in plant-available form

$T_{i,j}$ = total plant available S (crop S uptake + extractable soil sulphate) in sulphate treatment i and elemental S rate treatment j

$T_{i,o}$ = total plant available S in sulphate treatment i and elemental S^o rate 0

A_j = elemental S application rate in rate treatment j

The "apparent oxidation" of elemental S products used in Experiment A

for the period of May 1986 to May 1987 is illustrated in Fig. 4. Apparent oxidation of 95% S^o varied with rate of application (lower rates are subject to larger errors) and varied between 50 and 60%. The 90% S^o products exhibited considerably lower oxidation rates. There was an enhancement of oxidation of one of the two 90% S^o over the winter period, whereas the other source exhibited no apparent oxidation.

DISCUSSION AND CONCLUSIONS

The results demonstrated considerable differences in the effectiveness of various elemental S products and ammonium sulphate both in the year of application and the subsequent year. Ammonium sulphate was an efficient source in alleviating S deficiency in the year of application. Although some residual sulphate at the end of the year of application was present at the high sulphate rate treatments, responses to sulphate in the second year may also be attributed to S mineralized from stubble from the previous crop. This possibility is currently under investigation.

The 95% S^o powder was rapidly converted to plant-available sulphate as evident from crop S concentrations. Furthermore, since application of supplemental sulphate to the S^o powder elicited no further yield increase, it is clear that this elemental S product effectively alleviated S defifiency, even at application rate of 30 kg ha^{-1}. Evidently, oxidation proceeded rapidly enough to supply S requirements even during the early part of the growing season in the year of application. The relatively rapid rate of oxidation observed in the S^o powder can be attributed to its extremely fine particle size (in the order of 2.5 micron in diameter) and to the effective dispersion of the elemental S paricles in the soil when applied in suspension form (Janzen and Bettany, 1986). Soil sulphate data suggest that the short-term effectiveness of the S^o powder is comparable to that of sulphate under the conditions of the study.

The two S^o+bentonite products demonstrated only limited conversion to sulphate over the growing season. Even when applied at 120 kg S ha^{-1} these products only partially alleviated S deficiency. The relative slow apparent oxidation of these products can probably

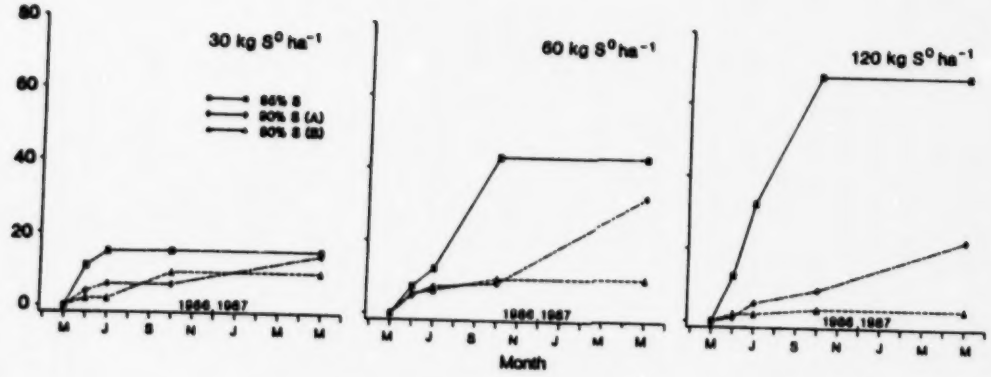

Fig. 4. Apparent oxidation of elemental S from the three elemental S sources used in Experiment A (based on 0-30 cm depth).

be attributed to the ineffective mixing of the individual elemental S particles into the soil (Janzen and Bettany, 1986). The methods of application used in this study (shallow incorporation vs simply broadcast) did not alter the efficiency of these products when spring applied. Fall application made in 1987 will be evaluated next year. One of the two S^{o}+bentonite products exhibited accelerated oxidation rates over the winter, however, with no benefit on barley yields. This study is continued for a third year at which time overall strategies regarding short-term and long-term S fertilization will be finalized. Perhaps it is significant to note at this time that selection of the products and strategy will be accompanied by both agronomic as well as economic considerations. Hence, agronomically, selection of rotations, which may not include crops susceptible to S deficiency, may negate the use of an elemental S source, especially if it were to be supplemented by ammonium sulphate in the year of application. Method of application, such as spraying or an extra pass over the field prior to seeding after all other activities are finished may not be agronomically efficient and may add extra costs. Considerations for fall application will be assessed next year. Economically, the situation should be assessed both in terms of return on extra investment both in the year of application and subsequent years. However, in certain cases, the initial capital investment for residual benefits may not fit the economic plans of farmers. A broad economic comparison of ammonium sulphate, 95% S^{o} and 90% S^{o} is offered in Table 10 on the basis of available yield data and assumed prices.

LITERATURE

Janzen, H.H. and Bettany, J.R. 1986. Release of available sulphur from fertilizers. Can. J. Soil Sci. 66:91-103.

Janzen, H.H., Karamanos, R.E., and Ramsay, P. 1987. Short-term oxidation of several elemental sulphur fertilizers in central Alberta, pp 240-254 in Proceedings 24th Annual Alberta Soil Science Workshop, Calgary, Alta.

Karamanos, R.E., Janzen, H.H., and Ramsay, P. 1987. Canola yield responses to several sulphur sources - A one year's experience, pp 174-195 in Markets - Soils and Crops. 1987 Soils and Crops Workshop, University of Saskatchewan, Saskatoon, Sask.

Table 10. Comparison of marginal returns on marginal fertilizer cost in the rotations of Experiment A

Variables*	Control	Ammonium sulphate 20 lb/ac		S° powder(95%) 30 lb/ac	90% S° 30 lb/ac
Canola yield (bu/ac	10.4	22.6		25.6	11.2
ΔR (bu/ac)	-	12.2		15.2	0.8
ΔR, $ ($4.5/bu)	-	54.9		68.4	3.6
ΔC, $	-	3.6#		12.6@	4.9#
ΔR / ΔC	-	15.3		5.4	0.7
		Application			
		1986	1987		
Barley yield (bu/ac)	64.9	69.3	72.1	71.9	65.4
ΔR (bu/ac)	-	4.4	7.2	7.0	0.5
ΔR, $ ($1.25/bu)	-	5.5	9.0	8.75	0.63
ΔC, $	-	-	3.6	-	-
ΔR / ΔC - year	-	-	2.5	-	-
ΔR / ΔC - rotation		16.8	8.9	6.1	0.8

* ΔR = Δ Return (treatment - control); ΔC = ΔCost (fertilizer rate X cost per unit)

\# $0.18 lb^{-1} S

@ $0.42 lb^{-1} S f.o.b. Lethbridge.

SOIL ACIDIFICATION RESULTING FROM FORAGE FERTILIZATION[1]

J.T. Harapiak and N. Flore[2]

Relatively few of the field experiments that are carried out in Western Canada are designed to test the cumulative impact of annual fertilizer treatments on the soil to which they applied. It is unfortunate that this phase of research is ignored since the application of fertilizer can have an influence on soil quality. The potential of nitrogen to acidify the soil is one of the most common concerns related to fertilizer application.

Experimental Sites

Some of the field research trials conducted by WESTCO agronomists have been deliberately maintained for extended periods of time so that the effect of successive fertilizer applications could be assessed. A series of long-term, replicated, randomized block design forage (bromegrass) trials established in the thin black soil zone (Carstairs, Alberta) on a resorted glacial till loam soil provided an opportunity to measure the impact of a wide range of nitrogen rates and sources on soil acidity. The first trial (experiment #8) comparing rates of ammonium nitrate ranging from 0-300 lbs N/acre established in 1968 was subjected to intensive soil sampling after sixteen years of fertilizer application (i.e. 1968). The second trial at this location (experiment #145) was established in 1974 to compare urea and ammonium nitrate applied at a rate of 100 lbs N/acre at four different times of application (i.e. early fall, late fall, early spring and late spring). This site was sampled after eleven years (i.e. 1984). The final study (i.e. experiment #186) was established in 1979 to compare four nitrogen sources (i.e. ammonium nitrate, urea, calcium nitrate and ammonium sulphate applied at relatively high rates of fertilization (i.e. 150 and 300 lbs N/acre). This trial was soil sampled after only five years (i.e. 1983) of fertilizer applications.

Soil Sampling Technique

Each of the treatments was replicated six times and each of the replicates were sampled individually. A separate series of shallow and deep samples were collected. The shallow sampling consisted of three depths (i.e. 0-2", 2-4" and 4-6"). The deep samples were more typical of the types of samples that would normally be collected if a field were to be routinely soil tested (i.e. 0-6", 6-12", 12-24") plus two additional depths (i.e. 24-36" and 36-48"). These samples were submitted to the Alberta Soils and Nutrition Laboratory

1. Presented at the 31st Annual Manitoba Soil Science Meeting, January 5-6, 1988, Winnipeg, Manitoba.
2. Westco Fertilizers, P.O. Box 2500, Calgary, Alberta, T2P 2N1

(formerly ASFTL) for routine soil analysis (Laverty and Bollo-Kamara, 1988).

Average Yield Data

The main emphasis of this paper will be on the data collected from the nitrogen rate study (i.e. experiment #8) for which the average yield data is presented in Figure 1. It should be pointed out that the majority of the yield increase was accounted for by a rate of 100 lbs/N acre. Most producers would apply considerably less nitrogen to their hay fields. As will be seen later in this paper, the application of excessive amounts of nitrogen (i.e. exceeding 100 lbs N/acre) resulted in much more rapid soil acidification than did the lower rates that were more typical of rates currently being applied by prairie farmers.

Rate of Acidification

The impact of sixteen years of applying various rates of nitrogen on the pH as determined in a soil:water (1:2) mixture (Laverty and Bollo-Kamara, 1988) of the shallow samples is illustrated in Figure 2. It was obvious that for the surface layer (0-2"), the drop in soil pH was closely related to the rate of N application up to an annual rate of 200 lbs/ac. Above this rate, the soil appeared to buffer against a further drop in soil pH. The pH of the 2-4" layer did not decline below that of the unfertilized treatment until the rate of N application exceeded 100 lbs/ac. For the 4-6" layer, application of rates of N up 200 lbs/ac resulted in a slight increase in soil pH.

The influence of nitrogen fertilizer application on the soil pH of the deeper samples is illustrated in Figure 3. It is obvious that the soil pH values were highly influenced in the 0-6" layer. As illustrated in the information presented in Figures 4 and 5, the rate of acidification of the 0-6" layer appeared to differ at rates above and below 100 lbs N/ac. The calculated regression lines indicated that over a sixteen year period, for rates of N up to 100 lbs/ac applied annually, the drop in pH amounted to 0.004 units per lb of N. At rates between 100-300 lbs N, the drop in pH over the same period amounted to 0.008 units per lbs of N. This suggests that for the 0-6" layer, the rate of soil acidification at excessive rates of N application was doubled.

After sixteen years of ammonium nitrate application at the rate of 100 lbs N/ac, the actual pH of the surface soil (i.e. 0-6") had only declined by 0.3 units (i.e. 7.3 vs 7.0). Similar or larger declines in the pH values of the 0-6" layer have been recorded for comparable periods of application, but at much lower rates of nitrogen for annual crop production (Campbell and Zentner, 1984; Janzen, 1986). It is possible that the annual mixing of the plow layer by cultivation may predispose the soil to more rapid acidification. Since it was only the uppermost portion of the soil (i.e. 0-2") that

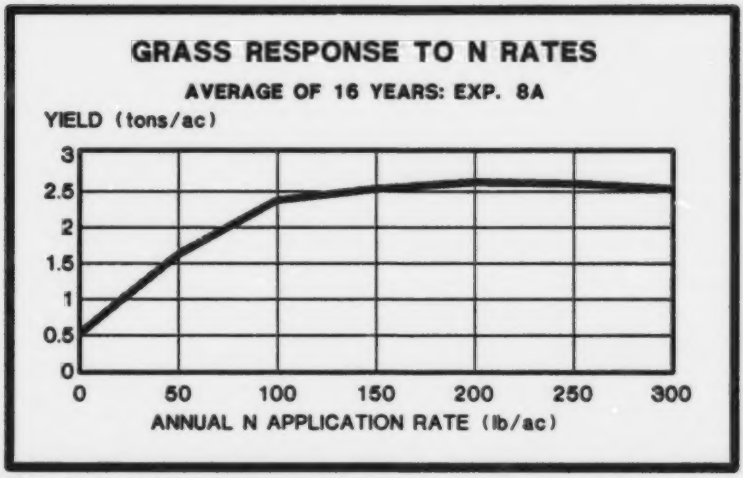

Fig. 1. Average response of bromegrass to increasing rates of ammonium nitrate application in the thin black soil zone (Carstairs, Alberta). Based on sixteen years of data.

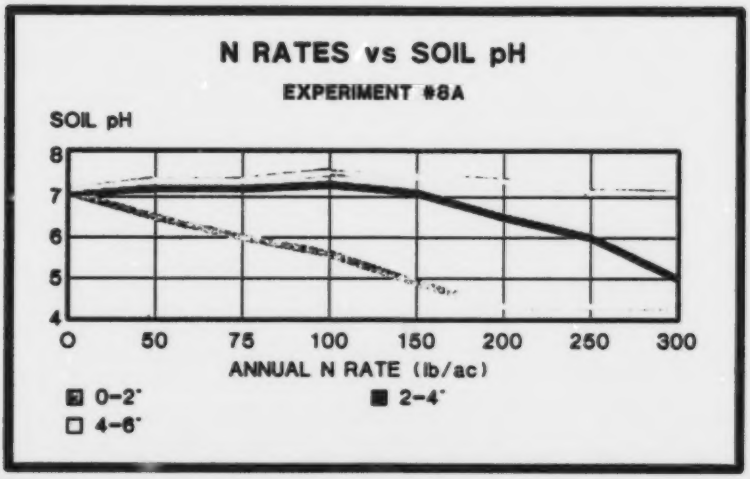

Fig. 2. Soil pH of three consecutive surface layers (i.e. 0-2", 2-4" & 4-6") as influenced by increasing rates of ammonium nitrate application over sixteen successive years of nitrogen application.

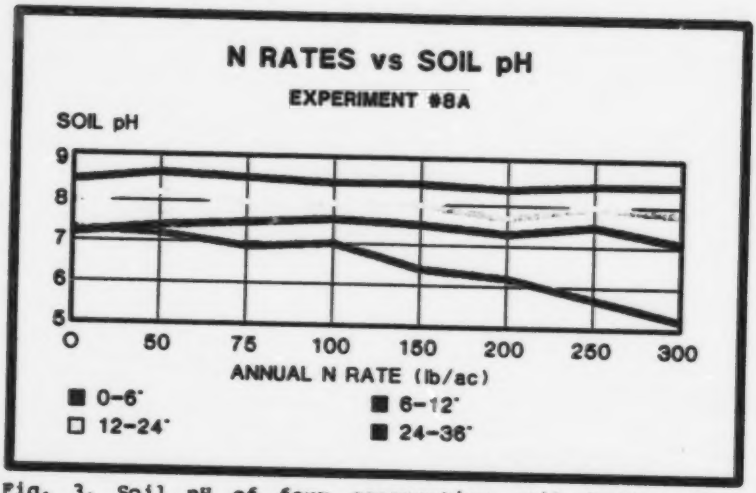

Fig. 3. Soil pH of four consecutive soil depths (i.e. 0-6", 6-12", 12-24" & 24-36") as influenced by sixteen successive years of ammonium nitrate application.

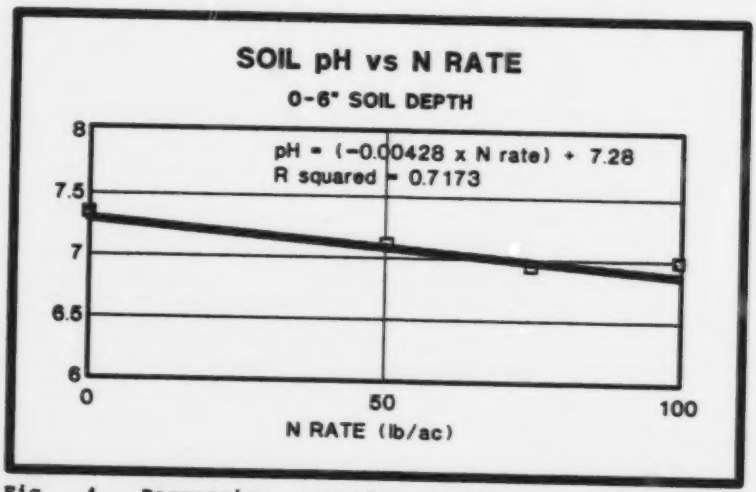

Fig. 4. Regression equation indicating relationship between soil pH (0-6") and influence of sixteen successive years of conventional rates (i.e. 0-100 lbs N/acre) of nitrogen application.

came into intimate contact with the fertilizer, this portion was most vulnerable to acidification (see Figure 2). Limiting the amount of soil coming in direct contact with the fertilizer to the extreme surface as would be the case in forage stands, rather than mixing it into direct contact with more of the soil through tillage as occurs in annually cultivated soils, may have helped to buffer against the full expression of the potential acidifying power of the volume of nitrogen fertilizer that was applied.

It should be noted that if the pH of the 0-6" layer is calculated for the 100 lb N rate using the regression lines (see Figures 4 and 5), the corresponding pH values are 6.8 and 6.9. This translates into calculated drop in pH ranging between 0.4 and 0.5 units.

For the 6-12" layer, the regression lines attempting to describe the impact of sixteen cumulative nitrogen applications on soil pH are illustrated in Figures 6 and 7. At lower rates of N application, it appeared that the pH of the 6-12" layer was actually increasing. Higher rates of fertilizer application (i.e. 100-300 lbs N/ac), resulted in a gradual acidification of the 6-12" layer.

It appeared that the rate of nitrogen application did not have any consistent influence on the soil pH values that were measured below the 6-12" layer.

Urea vs Ammonium Nitrate

Comments in the literature (Tisdale, et al, 1985; van Lierop and Tran, 1979; Bordeleau, 1979) suggest that ammoniacial sources of nitrogen are more acidifying than non-ammoniacal sources of nitrogen. On this basis, it would be assumed that urea would be more acidifying than ammonium nitrate. Data summarized in Figure 8 indicates that after eleven years of N application at the rate of 100 lbs N/ac, ammonium nitrate was actually more acidifying on the 0-6" layer than was urea (7.0 vs 7.3). In these trials, on average, urea was only 75% as effective as ammonium nitrate in terms of increasing the yield of grass forage. This reduced efficiency of urea was attributed to the fact that it was more vulnerable to atmospheric volatilization losses of ammonia. It would therefore appear that urea was less acidifying than ammonium nitrate because less of the N fertilizer that was applied as urea actually entered the soil system. Similar trends were observed in the shallower samples with the bulk of the acidification occurring in the 0-2" layer.

Four Nitrogen Sources

The relative impact of four nitrogen sources (ammonium nitrate, urea, calcium nitrate and ammonium sulphate) over a relatively short period of time (i.e. 5 years) applied at relatively high rates of N (i.e. 150 and 300 lbs/ac) is summarized in Figure 9. It is obvious that ammonium sulphate was the most acidifying of the four nitrogen sources while

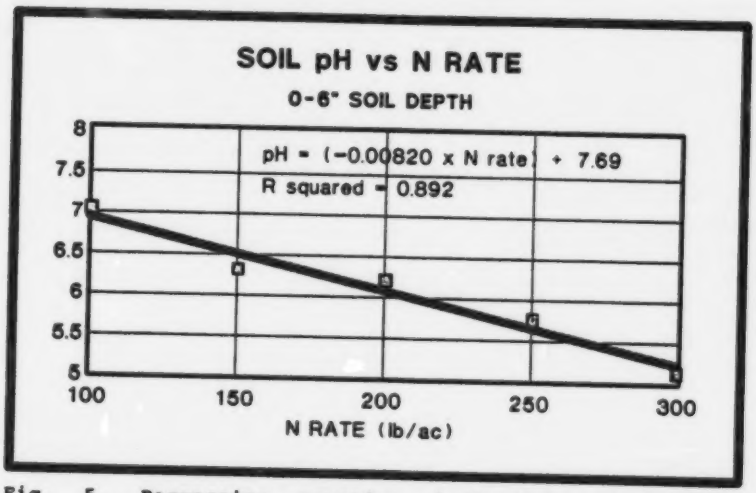

Fig. 5. Regression equation indicating relationship between soil pH (0-6") and influence of sixteen successive years of excessive rates (i.e. 100-300 lbs N/acre) of nitrogen application.

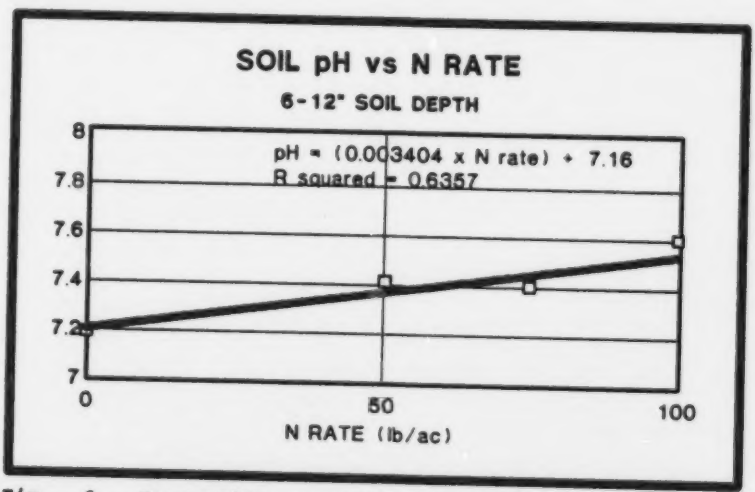

Fig. 6. Regression equation indicating relationship between soil pH (6-12") and influence of sixteen successive years of conventional rates (i.e. 0-100 lbs N/acre) of nitrogen application.

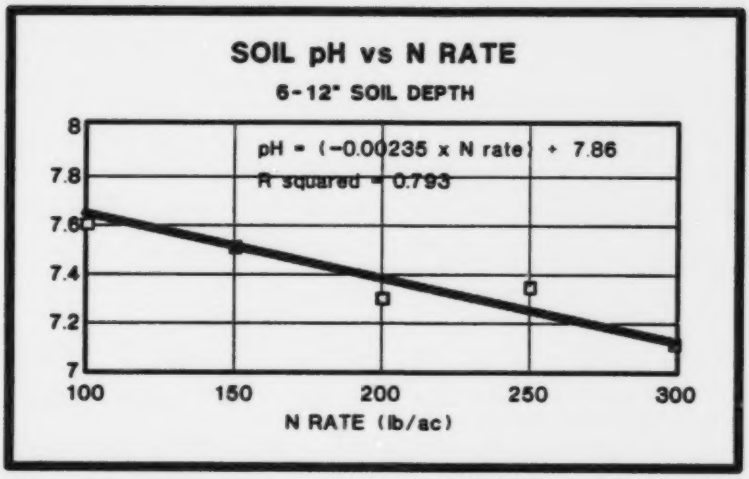

Fig. 7. Regression equation indicating relationship between soil pH (6-12") and influence of sixteen successive years of excessive rates (i.e. 100-300 lbs N/acre) of nitrogen application.

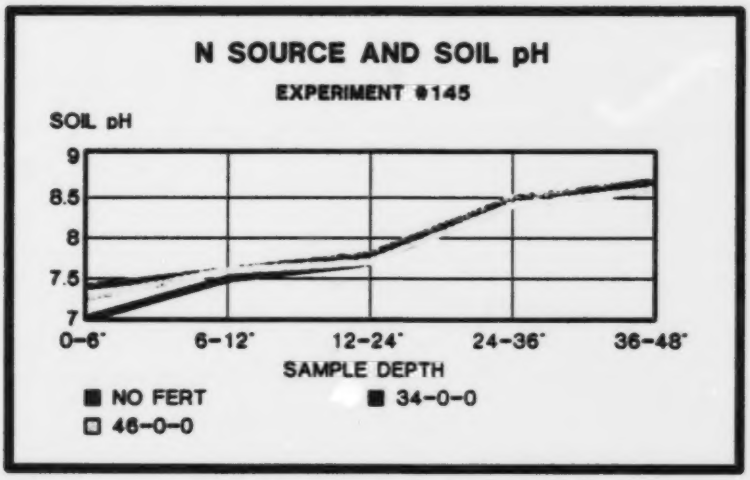

Fig. 8. Soil pH of five consecutive depths as influenced by eleven successive years of ammonium nitrate and urea application (i.e. 100 lbs N/acre applied annually).

calcium nitrate increased the pH slightly. The bulk of the pH modification was accounted for in the 0-6" layer.

Calcium and Magnesium

In most situations, a drop in soil pH was accompanied by a drop in calcium and magnesium levels as determined in an ammonium acetate (1:5) extract. It appeared that magnesium may have been more readily mobilized by nitrogen fertilizer application than was calcium. This observation may have implications for pasture fertilization in situations where cattle are vulnerable to magnesium deficiencies (i.e. "grass tetany").

For a more detailed report of the behaviour of calcium, magnesium and other nutrients in these same nitrogen fertilized soils, the reader is referred to a companion paper that was presented at the Saskatchewan "Soils and Crops Workshop" (Harapiak and Flore, 1988).

Method of pH Analysis

In addition to the 1:2 (soil:water) mixture determination of soil pH, selected samples were subjected to pH determinations conducted in a dilute (0.01M) $CaCl_2$ solution. The results obtained by the two methods of pH determination for the 0-6" samples are illustrated in Figure 10. The relationship between the pH values obtained by the two methods of determination for the surface (0-6" samples) as well as for all depths is described by the following formulas:

Surface (0-6")

$pH\ (CaCl_2) = pH\ (H_2O) \times 1.0093 - 0.808\ (R^2 = 0.99)$

All Depths (0-6", 6-12", 12-24", 24-36" & 36-48")

$ph\ (CaCl_2) = pH\ (H_2O) \times 0.956 - 0.424\ (R^2 = 0.99)$

Total Nitrogen Content

Total nitrogen levels were determined by the Kjeldhal method for the 0-6" and 6-12" layers. As indicated in Figure 11, the application of increasing amounts of N over a sixteen year period resulted in a steady increase in the total N content of the 0-6" layer. The regression equations that describe the relationship for the two surface layers were calculated to be as follows:

0-6"

$Total\ N\ (\%) = (0.00032 \times N\ rate) + 0.34\ (R^2 = 0.95)$

6-12"

$Total\ N\ (\%) = (0.00023 \times N\ rate) + 0.14\ (R^2 = 0.54)$

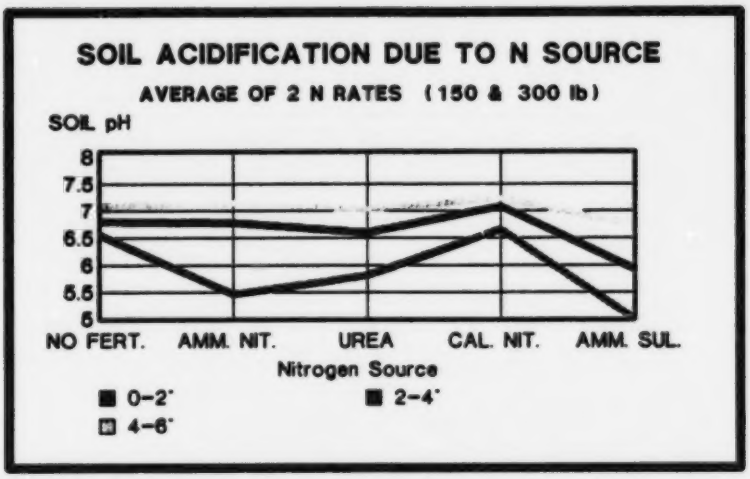

Fig. 9. Soil pH of three consecutive surface layers (i.e. 0-2", 2-4" & 4-6") as influenced by four different nitrogen sources applied for five consecutive years at excessive rates of nitrogen (i.e. 150 & 300 lbs N/acre annually).

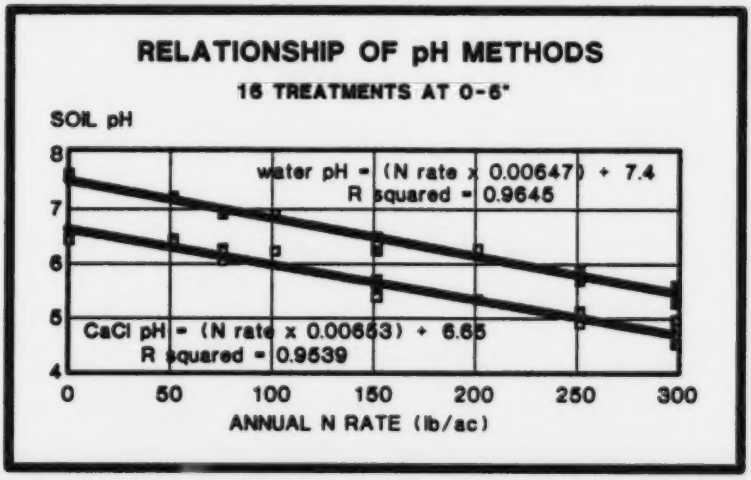

Fig. 10. Soil pH of the surface layer (0-6") determined (1:2 mixture) in water and in a dilute $CaCl_2$ solution as influenced by sixteen consecutive years of application of a wide range of rates of ammonium nitrate.

These equations suggest that over a period of sixteen years there was a substantial build-up of the total N content of the soil as a direct result of fertilizer nitrogen application. Based on the assumption that an acre furrow slice (i.e. 0-6") weighs 2,000,000 lbs, the N content of the unfertilized layer would amount to 6,800 lbs/acre. After sixteen years of fertilizer application at the rate of 100 lbs N/acre, the total N content increased to 7,440 lbs/acre for a net gain of 640 lbs of N. This suggests that of the 100 lbs of N that was annually applied, on average, 40 lbs/acre were accounted for in the total N pool of soil nitrogen. This represents a rather large pool of potentially mineralizable nitrogen that could be available for future crop production. Additional amounts of total N also accumulated in the 6-12" layer in response to nitrogen fertilization. However, the relationship between total N content and rate of N application for the 6-12" layer was quite erratic.

The average grass forage yield in response to the application of 100 lbs N/ac amounted to 2.4 tons/ac. Assuming an average protein content of 7.5%, the N content of the harvested forage amounted to 58 lbs/ac. This amount less the estimated average N content of the check treatment (i.e. 10 lbs N/ac), suggests that the N recovery in the crop for the 100 lbs/ac N rate amounted to 48 lbs/year. This rate of recovery of the applied N was low compared to the recovery rates of 45% for urea and 55% for ammonium nitrate reported by Cairns (1968). It is obvious that the amount of N being tied-up in the soil N pool of the 0-6" soil layer was almost equal to the amount being recovered by the crop (i.e. 40 vs 48 lbs/acre at the 100 lbs/ac rate of fertilization). In total, 88% of the applied nitrogen was accounted for in these two components.

Organic Matter Content

The organic matter content of the three shallow surface layers (i.e. 0-2", 2-4" and 4-6") was also determined by the ignition method (Laverty and Bollo-Kamara, 1988). There appeared to be a tendency for the organic matter content of all three layers to increase as the rate of N applied increased. In the case of the 0-2" layer, the increase in organic matter content was most dramatic for the first few increments of nitrogen application (see Figure 12). The following regression equations describe the relationship between rate of fertilizer application over a sixteen year period and the organic matter content of the surface layers:

0-2" (0-100 lbs N/ac)

$\%\ OM = (0.0246 \times N\ rate) + 9.72\ (R^2 = 0.95)$

0-2" (100-300 lbs N/ac)

$\%\ OM = (0.0033 \times N\ rate + 11.81\ (R^2 = 0.39)$

2-4" (0-300 lbs N/ac)

$\%\ OM = (0.0019 \times N\ rate) + 8.70\ (R^2 = 0.51)$

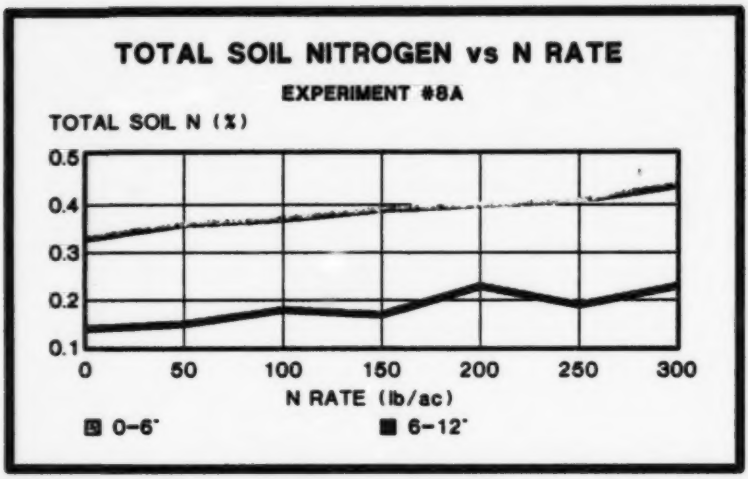

Fig. 11. Total N content (%) of two soil layers (i.e. 0-6" & 6-12") as influenced by sixteen successive years of application of a wide range of ammonium nitrate rates.

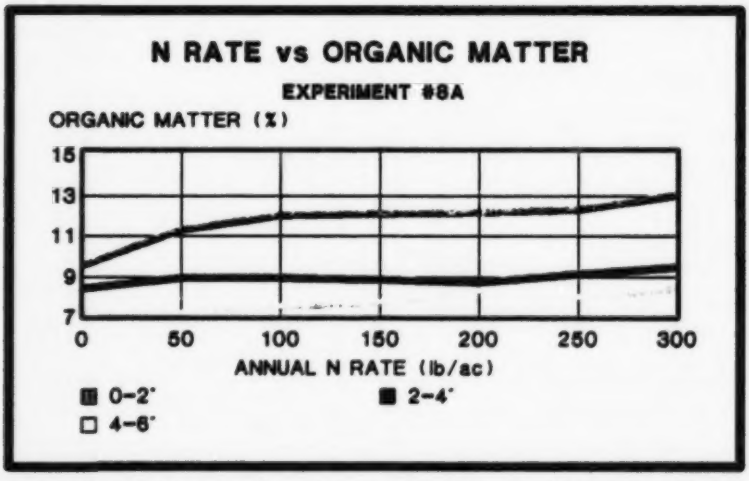

Fig. 12. Total organic matter content (%) of three consecutive surface layers (i.e. 0-2", 2-4" & 4-6") as influenced by sixteen successive years of application of a wide range of ammonium nitrate rates.

4-6" (0-300 lbs N/ac)

% OM = (0.0035 x N rate) + 7.22 (R^2 = 0.70)

It is important to note that the annual application of N at the rate of 100 lbs/acre over a relatively short period of time (i.e. sixteen years), the organic matter content of the 0-2" layer increased from 9.5% to 12.0%. This is a very significant improvement of the organic matter status of this soil within a rather brief time frame.

It should also be noted that it was recently reported (Goh et al, 1987) that a significant build-up in the organic matter content of the surface layer occurred after a relatively brief period (i.e. five years) of fertilizer application to a grass forage stand. Samples collected from experiment #186 formed the basis of this study.

SUMMARY

Acidification

- The greatest drop in pH occurred in the 0-2" layer accompanied by a slight increase in pH in the 2-4" and 4-6" layers at normal rates of fertilization.
- A drop in pH occurred in the 2-4" layer at excessive rates of fertilization.
- As a result of annual N applications over a sixteen year period, pH of the 0-6" layer declined as follows:

  100 lb/ac - 0.3 units
  200 lb/ac - 1.0 units
  300 lb/ac - 2.0 units

- The decline in pH was greater from applications of ammonium nitrate than for urea.
- The greatest drop in soil pH occurred with the use of ammonium sulphate.
- Calcium nitrate consistently increased soil pH values in the surface (0-6") layer.
- At higher rates of application, ammonium sulphate was more than twice as acidifying as ammonium nitrate and three times worse than urea.

Calcium

- Applications exceeding 100 lb N/ac resulted in a drop in Ca levels in the 0-6" layer and an increase in Ca levels in the 6-12" and 12-24" depths.

- Levels of Ca declined most dra[illegible]tically in the 0-2" layer and appeared to increase in the [illegible]6" layer while a decline in Ca in the 2-4" level was detected at rates exceeding 200 lb N/ac.

Magnesium

- Application of increasing rates of N resulted in a steady decrease in the levels of Mg in the 0-6" layer.

- It appeared that Mg was more readily mobilized by N fertilization than was Ca.

Mineral N

- Build up of NO_3-N and NH_4-N (i.e. 2N KCl extractable) in soil was minimal at rates up to 100 lb N/ac.

- At higher rates of application a bulge in NO_3-N occurred in the 6-12" and 12-24" layers.

- In the surface layer (0-6"), the highest levels of NO_3-N occur in the 4-6" layer.

- The bulge in NH_4-N at excessive rates of N application was concentrated in the 0-2" layer.

- At rates exceeding 250 lbs N/ac, an increase in NH_4-N was detected at the 2-4" level.

Total N

- A steady build-up in the total N content of the 0-6" layer resulted from increasing rates of N application.

- The increase in the total N content of the 6-12" layer was more erratic but may nevertheless be significant.

Organic Matter Content

- A significant increase in the organic matter content of the surface layers resulted from annual applications of increasing amounts of N.

- The largest increase occurred in the 0-2" layer (9.5% - 13.0%).

- The greatest proportion of the increase was accounted for by application rates of 50 - 100 lb N/ac/year.

REFERENCES

Bordeleau, L. 1979. The pH and soil organisms. In Soil Acidity Liming and Plant Growth. Agriculture Canada Expert Committee on Soil and Water Management.

Campbell, C.A. and R.P. Zentner. 1984. Effect of fertilizer on soil pH after seventeen years of continuous cropping in Southwestern Saskatchewan. Can. J. Soil Sci. 64:705-710.

Cairns, R.R. 1968. Various forms of nitrogen fertilizer for bromegrass on a solonetz soil. Can. J. Soil Sci. 48:297-300.

Goh, T.B., M.J. Dudas, S. Pawluk and J.T. Harapiak. 1987. Physical, chemical and micromorphological effects of nitrogen fertilizers on chernozemic soils. Geoderma, 40:177-192.

Harapiak, J.T. and N. Flore. 1988. Influence of forage fertilization on soil nutrient distribution. Sask. Soils and Crops Workshop. Feb. 18-19, Saskatoon, Saskatchewan.

Janzen, H.H. 1987. Effect of fertilizer on soil productivity in long-term wheat rotations. Can. J. Soil Sci. 67:165-174.

Laverty, D.H. and A. Bollo-Kamara. 1988. Recommended Methods of Soil Analysis for Canadian Prairie Agricultural Soils. Alberta Agriculture, Soils and Animal Nutrition Laboratory.

Tisdale, S.L., W.L. Nelson and J.D. Beaton. 1985. Soil Fertility and Fertilizers. MacMillan Publishing Company, New York.

van Lierop, W. and T.S. Tran. 1979. Nature and causes of soil acidity. In Soil Acidity, Liming and Plant Growth. Agriculture Canada Expert Committee on Soil and Water Management.

ACKNOWLEDGEMENT

This project would not have been possible without the encouragement and strong support of Alberta Agriculture. The soil analyses conducted by the Soils and Animal Nutrition Laboratory was an essential aspect of making this important study possible. The co-operation of Don Laverty, Ed Redshaw and A. Bollo-Kamara was especially appreciated.

REPORT FROM THE PROVINCIAL SOIL TESTING LABORATORY

K.S. McGill
Manitoba Agriculture
Soil Testing Laboratory

New Soil Test Report Form

In January 1987, in response to concerns expressed by producers and other users of the Soil Testing services, a committee was drawn together to evaluate the existing soil test report form and design a new one. Members of the committee included the Head of the Soil Testing Laboratory, a producer, a computer programmer, the Manitoba Agriculture central soil fertility specialist, along with Agricultural representatives, a regional crop specialist and a farm management specialist and representatives from the Soil Science Department of the University, Agriculture Canada, and the fertilizer industry (both suppliers and dealers). The goal was to develope a format for the soil test report form which was more attractive, provide more information, was easier to read and understand and ultimately, more helpful to producers in making sound economic fertilizer management decisions.

The final product which was ultimately developed incorporated several major changes to address specific concerns.

1.) Change of color, size and layout to make the form more eye appealing and to have all the desired information on one sheet.

2.) Allow the producer the option of having his report printed in either Metric or Imperial units to reduce the mass of numbers previously printed and to make the data easy to understand by the individual concerned.

3.) Include results of all requested optional tests (micronutrients, secondary nutrients, organic matter) on the one report to eliminate more than one page reports.

4.) Provide the test results in graphical form ranging from very low to very high (in addition to numerical values) to give a visual interpretation of their meaning.

5.) Provide a seperate area for interpretive comments on the test results, on recommendations in general, and on the specific crop recommendations.

6.) Continue to provide two crop options plus "standard" and "target yield" recommendations for all common crops. In addition include an indication of the prices and costs assumed for the "standard" recommendations where available and provide recommendations for four different moisture supply conditions high lighting the "most probable" moisture condition for the specific field in question and the one assumed for the standard recommendation. This would give the producer greater flexibility in modifying his application rate to suit his own situation in terms of prices specific moisture conditions, and yield goals.

7.) Provide recommendations for nitrogen and phosphorus specific to the application techniques selected by the producer (spring or fall broadcast or band application for nitrogen; placed or band application for phosphorus).

The goal is to have the new reports in general use for the spring 1988 soil sampling season.

1987 Fall Soil Test Results

Fall farm soil sample submissions to December 31st, 1987, amounted to approximately 6500 fields, up about 40% over the previous two fall seasons. Data indicates only small changes in average nitrate-nitrogen levels in stubble field from that reported for the past couple of years, while the percent of fields receiving fertilizer sulphur recommendations continues to increase significantly. Phosphate and potassium levels remain relatively constant.

The average soil nitrate-nitrogen levels in stubble fields in the province in general and in five regions of the province, along with an indication of the "average" fertilizer nitrogen recommendation is given in Table 1 indicating little change from last year.

Table 1. Available Soil Nitrate-Nitrogen Levels and Average Fertilizer Nitrogen Recommendation in Five Regions of Manitoba

Region	Average Soil Nitrate-Nitrogen Level (kg/ha)		Average Fertilizer Nitrogen Recommendation (kg/ha) Fall 1987
	1986-87	Fall 1987	
Province Wide	38	40	70
Central	45	44	80
Interlake	52	43	80
Eastern	41	48	60
Southwest	32	35	60
Northwest	31	39	70

Table 2 shows the significant increase in percent of fields receiving a sulphur recommendation in the fall 1987 over the average for the past eight years. This continues a trend which has been apparent for the past two years (1).

Table 2. Percent of Fields in Five Regions of Manitoba Receiving a Fertilizer Sulphur Recommendation.

Region	% of Fields Receiving a Fertilizer Sulphur Recommendation for:			
	All Crops		Special Crops	
	8 Year Ave.	Fall 1987	8 Year Ave.	Fall 1987
Province Wide	4	13	12	24
Central	5	11	12	20
Interlake	6	15	18	31
Eastern	3	10	10	19
Southwest	4	15	11	25
Northwest	4	15	13	27

Table 3 gives an indication of the average available phosphorus and potassium test levels for the fall 1987 soil samples which are very similar to long term average levels (1).

Table 3. Average Available Soil Phosphorus and Potassium Levels in Five Regions of Manitoba (Fall 1987).

Region	Phosphorus level (kg/ha)	Potassium Level (kg/ha)
Province Wide	20	595
Central	21	660
Interlake	25	630
Eastern	25	595
Southwest	17	585
Northwest	19	480

Reference

1. McGill,K.S. 1986. Nutrient Trends in Manitoba Soils: A Summary of Results from the Provincial Soil Testing Laboratory. In Papers Presented at the 30th Annual Manitoba Soil Science Meeting, Manitoba Agriculture, Winnipeg, Manitoba.

Information Needs for Choosing Fertilizer Rates*

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Darrell M. Zbeetnoff

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University of Manitoba

Background

"Management Options for Low Price Grain Production" is a project jointly sponsored by the Faculty of Agriculture, University of Manitoba and the Manitoba Department of Agriculture. The study objective is to review the information available to farmers for making more efficient production decisions. The impetus for this study was generated by the tighter economic prospects facing grain farmers but the information needs are essential under all production situations.

One focus for the research has been to assess the adequacy of the information base for identifying economically optimal fertilizer rates. Yield response of field crops to nitrogen (N) is one of the more direct input-output relationships used to make farm expenditure decisions.

Economic Approach

The ultimate benefit of yield calibration to nitrogen rates for the farmer is to be able to predict the effect of added N on net crop revenues. "Economic efficiency" is the criterion used by agricultural economists to evaluate production options. The "economic optimum" is identifiable as that combination which maximizes net economic returns at the market prices of crop and inputs.

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* Paper presented at the 31st Annual Manitoba Society of Soil Science Meeting, Winnipeg, January 5 and 6, 1987.

Note that achieving the economic optimum is not the same as applying N at rates to maximize yield. Yield potential is only one component of the equation determining profit. Mathematically,

$$\text{profit} = (\overset{(1)}{\text{total yield/acre}}) * (\text{\$ per bushel}) - (\overset{(2)}{\text{total production cost \$ per acre}})$$

To maximize profit potential, the farmer should select a production target which maximizes the gap between (1) and (2), above.

The methodology of determining rate of N fertilization is analogous. To allocate N in the most efficient manner, the farmer maximizes

$$\text{profit}_N = (\text{total yield increase/acre due to N}) * (\text{\$ per bushel}) - (\text{total added N cost \$ per acre})$$

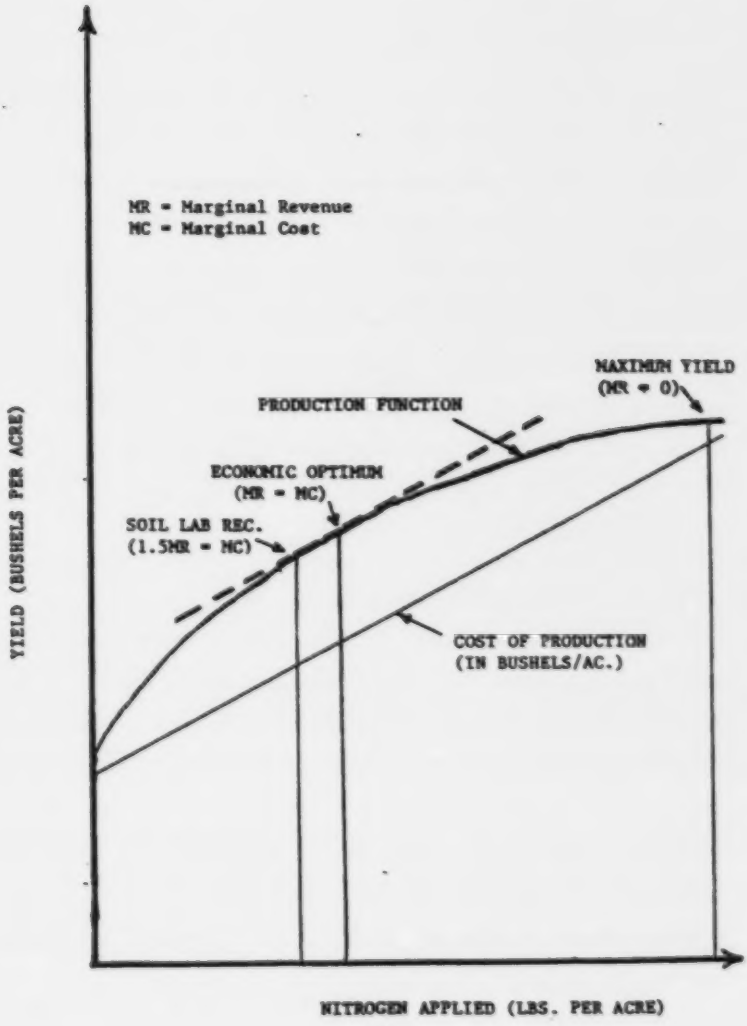
This approach identifies a unique production level for production functions characteristically like that in Figure 1. The optimal point is where the vertical distance between the production function and cost line is maximized or where the slope of the cost line is tangent to the production function.

Characteristics of Yield Responses to N

When N is the only limiting factor in plant growth, the range of yield responses about the expected value would be small i.e. there would be a high degree of certainty about the yield outcome. Unfortunately, the yield effect of N use is difficult to isolate and several other unquantified factors are strongly correlated with yield response for field crops in Manitoba. "Climate-Modified" target yield fertilizer recommendations for wheat, barley and oats take some of the moisture-related variance out of the yield response to N but it should

Figure 1

Characteristic Production Function of the Yield
N Relationship



be noted that those targets still fall short of being actual yield predictions (see Watt and Arthur, 1987). The remainder of this paper will highlight some economic implications of this variability in yield response to N.

When we recognize that yield response to N is essentially unpredictable in any particular year, the problem becomes: How to optimize fertilizer rate given the variability associated with yield response? At this point, the characteristics of the variability help to identify the economic fertilizer decision.

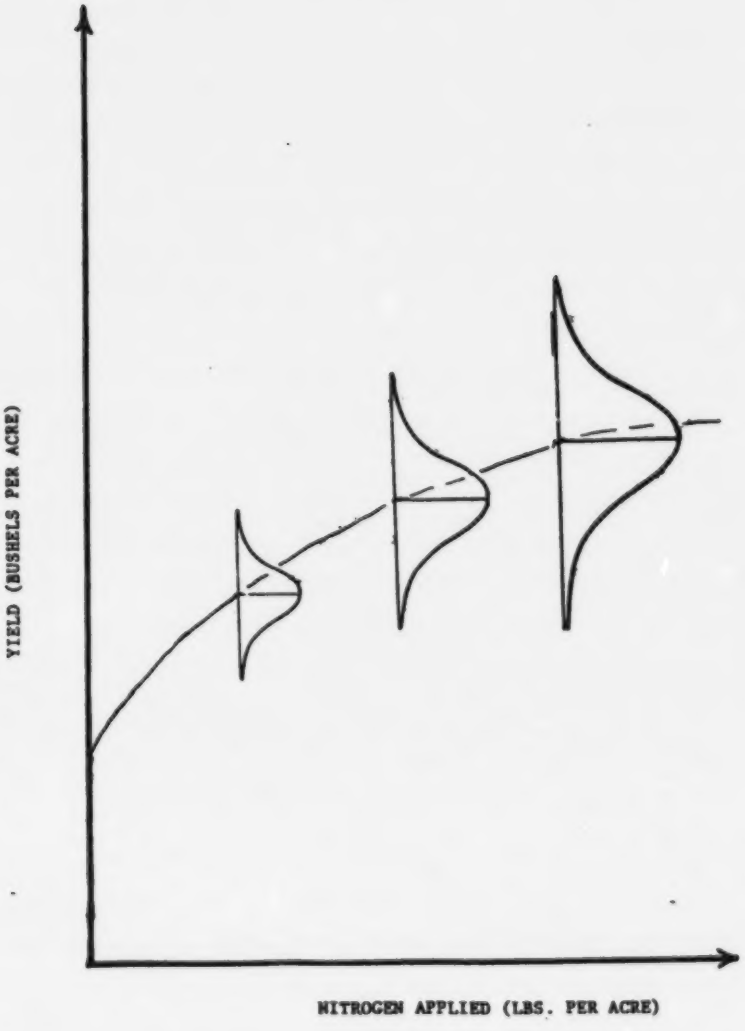
When the production function tracks expected yield response to N for generalized Manitoba field conditions, yield calibrations will be subject to greater error at higher N rates (Figure 2). Yield potential will be increased by high N availability when growth conditions are favorable but constrained by moisture and other factors when they are limiting. This is one way of saying that the use of N is often perceived to be risk-increasing since although the chances for higher profits are increased, the possibilities for negative returns also increase dramatically with added fertilizer costs.

Risk and Uncertainty

To deal with the increased variance in crop yields correlated with higher N rates, provincial soil laboratories, in establishing their target yield fertilizer recommendations, have used marginal revenue/marginal cost ratios greater than 1:1 (Saskatchewan Department of Agriculture, 1986; Alberta Department of Agriculture, 1985). Manitoba, for example, uses 1.5:1 in an effort to counter the increased risk by encouraging farmers not to strive for that last

Figure 2

Variability of Yield Response with Increased N Rate



additional increment of net revenue (Fehr, 1970). By backing down the production function, the recommendation does not target the economic optimum point of production but reduces the risk from an adverse yield outcome. Note that this assumption about decreased risk is directly related to the variability of yield response and has nothing to do with price variability.

There is the question however, of whether the risk characteristics are due to the effect of N use or due to factors not included in the calibration. When wheat, barley and oat target yield fertilizer recommendations are "climate-modified", average moisture availability for regions of the province are incorporated in the yield targeting. Figure 3 shows that moisture availability can be used to explain the range of variance about expected yield. Here we find that the yield variability characteristics for specific moisture conditions may be different. Reference to the data of Fehr, presented at this conference in 1970, shows barley response to N at different rates (Figure 4). The numbers in Table 1 indicate that this variability in yield response, as measured by the coefficient of variation, declined dramatically as N application rate increased.

If this statistical observation is characteristic of "climate-modified" target yield variance, then yield outcomes in response to N rate could be as variable at lower N rates as at higher N rates for given moisture conditions. In fact, at lower rates, variability would constitute a larger proportion of the expected yield, as Fehr (1970) found. Choosing production levels below the economic optimum for these crops would increase the risk of negative returns due to yield

Figure 3

Average Expected Pattern of Yield Responses to Different Moisture Levels

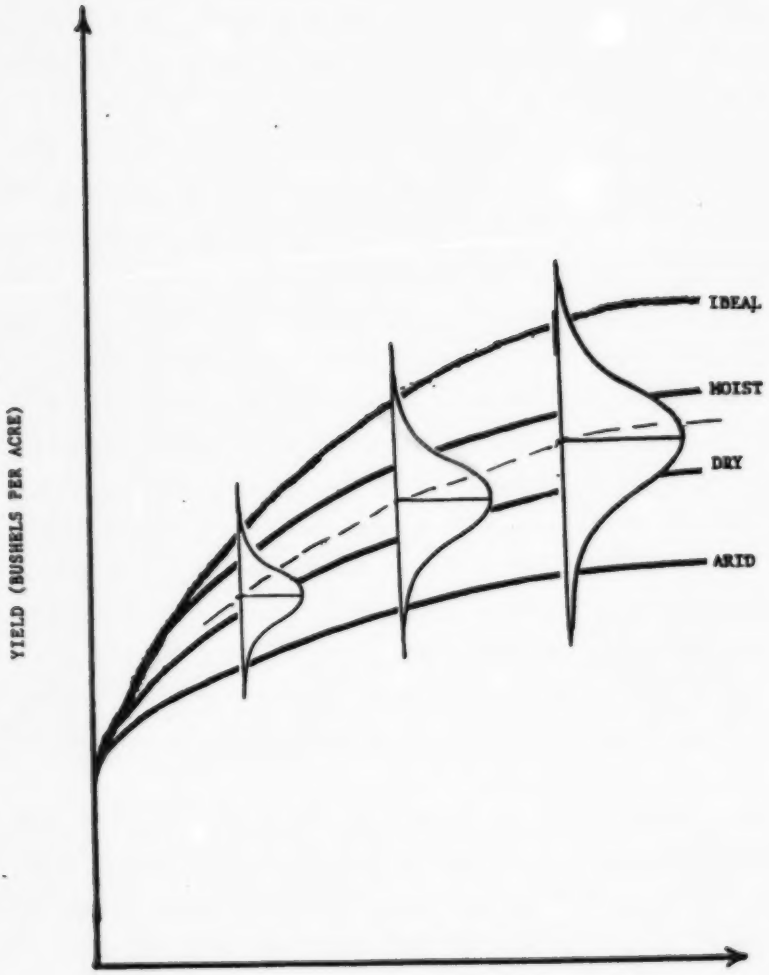
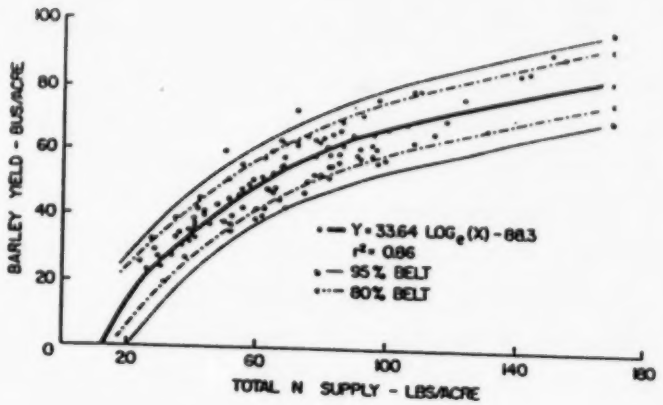


Figure 4

Variance of Barley Yields About Expected Yield



Source: Fehr, 1970, p. 127.

Table 1

Yield Variability - Barley 1962 to 1968

X lbs-N/ac	95% Y±	Standard Deviation	Coef. of[a] Variation (CV)
20	12.5 ± 13.0	6.63	53.0
60	49.4 ± 12.1	6.17	12.5
100	66.6 ± 12.3	6.28	9.4
140	77.9 ± 12.7	6.50	8.3
180	86.4 ± 13.1	6.68	7.7

[a] CV = (standard deviation/y) x 100.

Source: Fehr, 1970, p. 123.

variability. It follows that inflated marginal revenue - marginal cost ratios might not identify the profit maximizing or risk reducing production levels if moisture availability conditions can be anticipated. For each moisture level, the range of yield variation at different N rates may resemble that of Figure 5.

Interestingly, recent economic literature in the US has also reconsidered the conventional risk assumptions about fertilization practices. Indications are that yield variability may not increase, or only marginally, at higher N rates when the effect of N can be distinguished (Just and Pope, 1979). Studies on perceptions of yield risk reveal that Midwestern US farmers themselves regard N use to be risk reducing with the current information base (Sriramaratnam et al, 1987). As well, a farmer survey underway in Manitoba suggests that many of our own farmers consider N to be one of the last input areas to cut in the current economic environment.

Another way of examining the marginal analysis problem is illustrated in Figure 6, showing total expected yield revenues and operating costs in three regions of the province under dry moisture conditions in 1987. The HRS wheat yields at zero fertilization are based upon regional soil N reserves (McGill, 1987) and the yield expectations are based on the target yield tables of the provincial soil testing laboratory (Manitoba Provincial Soil Testing Laboratory, 1982). The points labelled A, A_1, and A_2 indicate the MR:MC ratio of 1.5:1. Points B, B_1 and B_2 represent production levels at MR:MC ratios of 1:1 i.e. the economic optimum. Note that at zero N rate, the Central and Southwest regions would have recovered operating costs

Figure 5

Estimated Yield Variation About "Climate-Modified" Target Yields

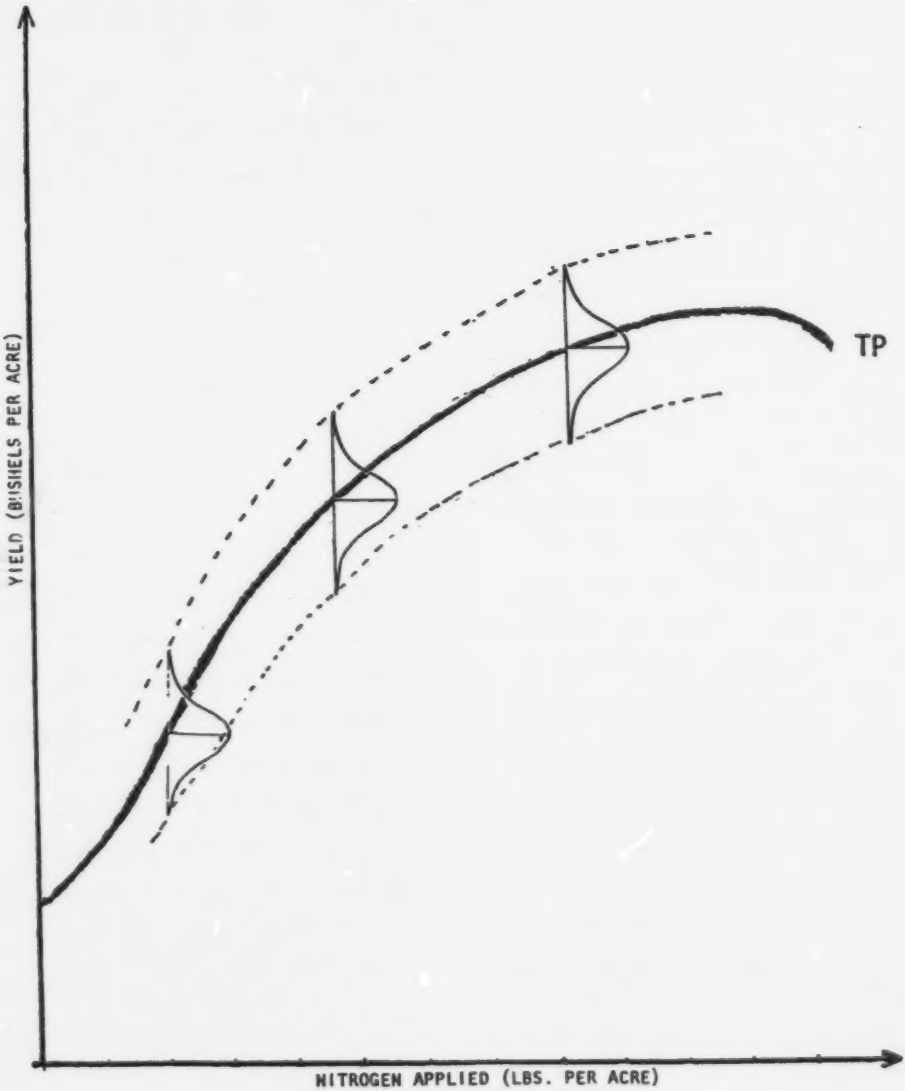
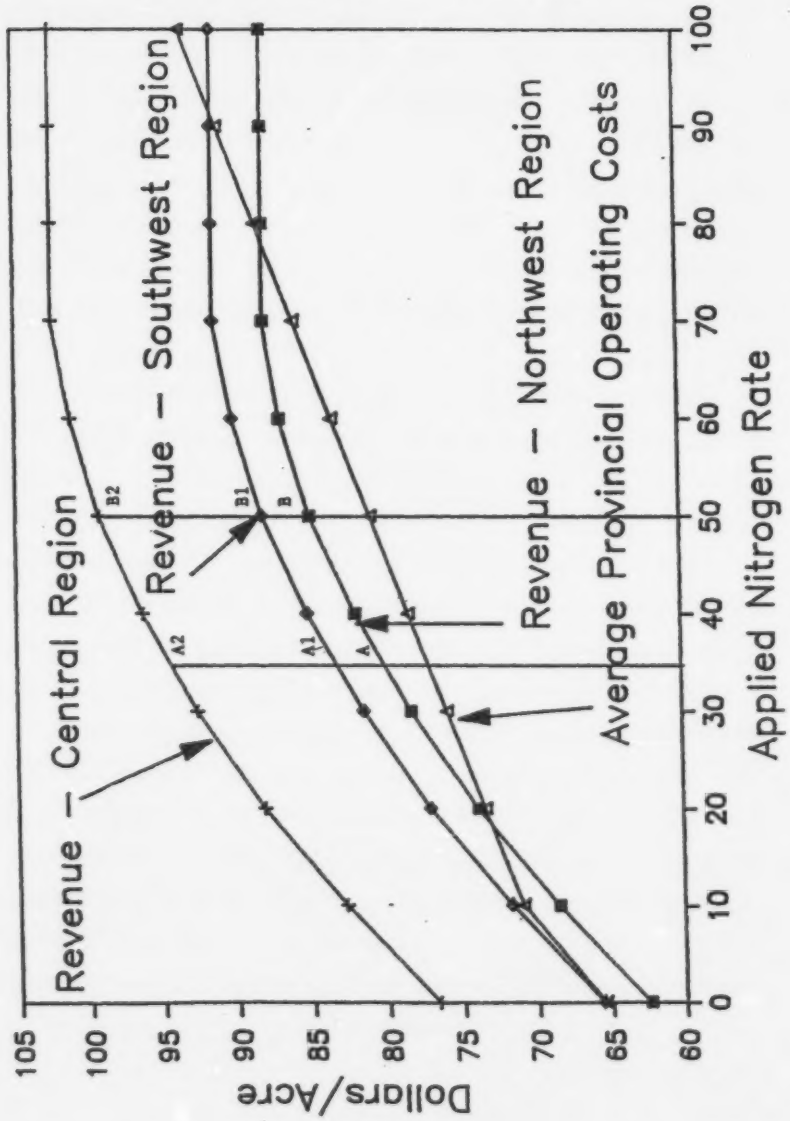


Figure 6

Revenue and Cost Expectations With Varying Levels of Applied N Under "Dry" Moisture Conditions



in 1987 whereas at least 20 lbs-N per acre, on average would have been required to produce any expectation of a positive net return on average soils in the Northwest region.

Now if we apply the observations noted above, two comments about the most efficient fertilizer rate can be made. First points A, are below the economic optimum production levels (points B) and would not have identified the maximum net revenue potential if target recommendations were followed. Keep in mind that nothing has been said about the likelihood of achieving points B production and revenue levels.

Second, however, if the variability of yield outcomes is constant at the two N rates, or declining or even slightly increasing but offset by the yield response from low to high N rate, points B also represent less risky production levels. A range of yield fluctuation about points B is less likely to produce negative yield returns than a similar yield fluctuation about points A. It follows that a farmer unconstrained in his purchase of fertilizer inputs and anticipating moisture conditions would have managed his risk exposure due to yield variability better by striving for the higher level of production.

The presentation so far may be distilled into one observation. A case has been made that the economic optimum is a more feasible production target for determining fertilizer rates if the variability characteristics of yield response can be narrowed by better predictive information on those factors, such as moisture availability, which are correlated with yield. This has highlighted the need for more research and a more comprehensive approach to data treatment and analysis.

Dealing with Yield Distribution

However, our investigation took us a step farther. We were interested in examining the economic effect of different distributions of yield outcomes about expected values assuming, for example, that in the short-run we acquired better predictive information on moisture availability.

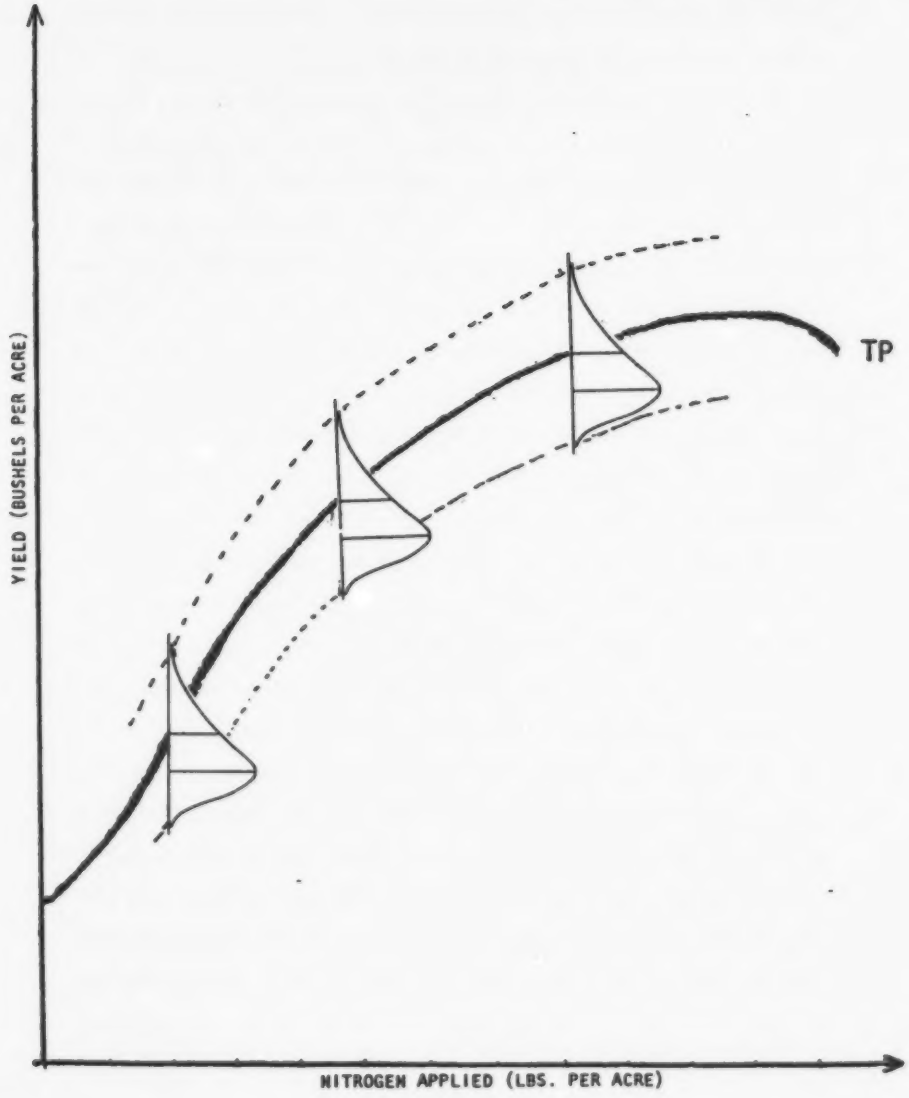
Lets refer back to Figure 5, which represents a wheat yield response curve to applied N for one particular moisture condition. Note that the distribution about the average or expected yield has been portrayed with a bell-shaped curve and further, it is assumed that, if the moisture availability is more or less predictable, the range of variability of yield outcomes does not increase substantially at higher N rates. In fact, this figure shows that variability decreases with higher applied N as did the barley yield response of Fehr, 1970.

The most frequent yield outcome in Figure 5 is the average. This is a statistical convenience, commonly assumed about data distributions of natural phenomena in many fields. There are however an infinite number of other shapes that a yield distribution could take about the average.

In Figure 7, we have the same production function, the same average expected yield but note that the most frequent yield outcome is actually below the average. The average is the same as in the previous figure only because in a minority of years, yields are considerably above the expected value thereby maintaining the average. Some work with yield data in econometric modelling at the Department

Figure 7

A Skewed Yield Distribution With the Most
Frequent Outcome Being Below the Average Yield

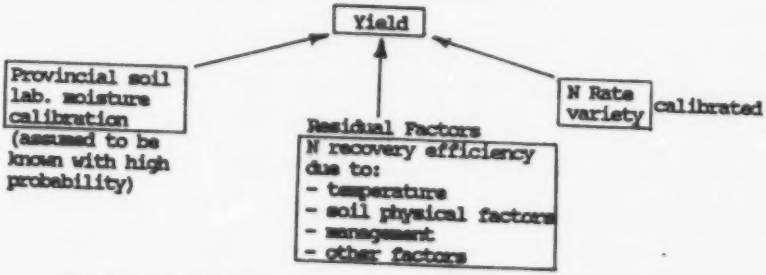


of Agricultural Economics, University of Manitoba suggests that yield distributions may be characterized like this. For our purposes, it is less obvious whether the most efficient production target would be the provincial recommendation, the economic optimum (where MR=MC) or at some other level.

Other distributions that could also produce the same expected yield but with obviously different fluctuations about that average are presented in Figure 8. We tested the economic implications of some of these.

It was more realistic in our view to consider a farmer's fertilizer program over a period of years rather than in just any one year (see Bock, 1984). After all, the earlier argument is that probabilities are important in choosing the fertilizer rate and if one looks at only one year, the probabilities are not given a chance to work.

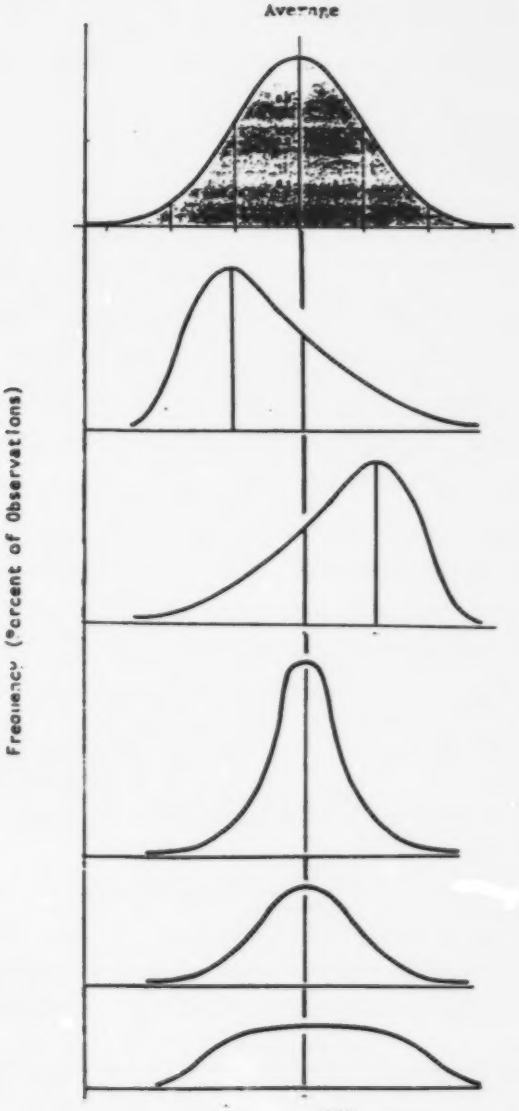
The hypothetical fertilizer N program was based on three years of yield experience. Breaking down the yield response factors conceptually, the following framework was used:



N recovery efficiency has an average value in Manitoba of 50 percent of actual N applied as fertilizer. This efficiency varies for

Figure 8

Frequency Distribution Exhibiting the Same Average Value
But With Different Dispersions of Observations About the Mean



some reasons not directly related to moisture availability and which may possibly not even be correlated with moisture (see de Jong and Rennie, 1967). As indicated in the Table 2, we have assumed several recovery efficiency distributions over the three years and then calculated overall revenues, costs and net revenues, using HRS #2 wheat prices of $2.45 per bushel, N at $0.25 per pound and average provincial operating costs as contained in the 1987 Crop Planning Guide (Manitoba Department of Agriculture, 1987). A sample calculation is presented in Table 3.

Economic Implications

The distributions can have a variety of interpretations. They may represent the yield experiences of different individuals at the same N rates over the three years. Alternatively, any particular distribution may reflect the combined result of a group of farmers or a region. Or for that matter, each distribution may characterize yields on a different soil type, for a set of management factors, etc.

Given an average recovery efficiency of 50 percent over the three years the efficiency outcomes were allowed to range between 20 percent and 80 percent of actual applied N. Some of these distributions point to fertilization rates in excess of provincial soil laboratory recommendations and the economic optimum. For example, a dispersed distribution with three year recovery efficiencies of 20 percent, 50 percent and 80 percent produced the highest net returns over the three year period at a rate of 80 pounds-N/acre (see Table 4).

The mechanism at work here is that the value of wasted N in low recovery years is more than outweighed by the value of yield increases in favorable high N recovery years.

Table 2

Target Wheat Yields With N Recovery Efficiency of:

N Rate (lbs/ac)	0.20	0.35	0.50	0.65	0.80
0	27.8[a]	27.8	27.8	27.8	27.8
10	29.1	30.1	31.1	32.1	33.1
20	30.3	32.2	34.1	36.0	37.9
30	31.4	34.1	36.8	39.5	42.2
40	32.3	35.7	39.1	42.5	45.9
50	33.1	37.1	41.1	45.1	49.1
60	33.8	38.3	42.8	47.3	51.8
70	34.3	39.2	44.1	49.0	53.9
75	34.5	39.6	42.6	49.7	54.6
80	34.7	39.9	45.0	50.3	55.3
90	34.9	40.3	45.6	50.9	56.3
100	35.1	40.6	46.1	51.5	57.1
110	35.2	40.8	46.4	52.0	57.6

[a] Bushels per acre.

Table 3

Yield Increases Attributable to N Fertilization at 60, 75 and 80 lbs-N/ac and a Comparison of Net Yield Returns at the Different Rates

Rate	Year	Cumulative Increase (bu/ac) With N Recovery Efficiencies of: 0.35	0.50	0.65	Per Acre Yield Returns @ $2.45/bu	Per Acre Total N Costs @ $0.25/lb	Per Acre[a] Yield Returns Minus N Costs
60	Yr 1	10.5			25.73	21.00	4.73
60	Yr 2		15.0		36.75	21.00	15.75
60	Yr 3			19.5	47.78	21.00	26.78
					111.26	63.00	47.26
75	Yr 1	11.8			28.91	24.75	4.16
75	Yr 2		16.8		41.16	24.75	16.41
75	Yr 3			21.9	53.66	24.75	29.91
					123.73	74.25	49.48
80	Yr 1	12.1			29.65	26.00	3.65
80	Yr 2		17.2		42.14	26.00	16.14
80	Yr 3			22.5	55.13	26.00	29.13
					126.92	78.00	48.92

[a] Includes $6.00/ac application cost for banding.

Table 4

	N Recovery Efficiency Frequencies:					Net Returns Over Operating (3 years) ($ per acre)			
	20%	35%	50%	65%	80%	MPL Recommend 60 lbs-N/ac MR:MO=1.5:1	Economic Optimum 75 lbs-N/ac MR:MO=1:1	Above Ec. Opt. 80 lbs-N/ac	Diff = Hi-Lo Net Returns
a		1	1	1		47.26	49.48*	48.92	2.22
b	1		1		1	47.25	48.01	48.43*	1.18
c	1			2		47.26	51.69*	49.17	4.43
d		2			1	47.26	49.70*	47.23	2.47
e		1		2		58.29	63.98*	61.91	5.69
f	1				2	69.30	71.73	73.67*	4.37
g		2		1		36.24	38.23*	36.43	1.99
h	2				1	25.20*	23.67	23.20	2.00

* Highest net returns per acre.

This may appear as a contradiction in terminology in view of the definition of the economic optimum. However, knowing the expected yield is not the only factor bearing on profit maximization. The shape of the yield distribution and the magnitude of the yield response at different N recovery levels is as important in a fertilizer program. And the economic analysis is as constrained by data gaps as is the prediction of yields response.

Looking over some of the other distributions, two of the eight result in higher net returns at N rates above the economic optimum, net returns are maximized at the economic optimum in five cases and the provincial target yield recommendation is favoured in one case. The differences in net revenues between high and low fertilization rates within any particular distribution can be as high as $5.69 per acre. That would appear substantial. In general, frequency distributions skewed to the right favour lower fertilizer rates, those skewed to the left indicate higher fertilizer rates to be more efficient.

If the distribution of yields about the average is unknown and it is different than the normal or bell-shaped curve, then a farmer's fertilizer program will not necessarily take probabilities into best account. Total net revenues can be higher or lower for similar average yield expectations, depending on the frequency distribution and for otherwise similar levels of risk (e.g. cases (a) to (d), Table 4).

Second, one would expect that some farmers are consistently achieving N recoveries efficiencies like (e) and (f) while others are

experiencing efficiencies like (g) or (h). Their fertilizer rate strategies should differ. And there are farmers achieving average N recovery efficiencies above 50 percent due to their crop and varietal selection, rotations, management and soils. These farmers do not get too much assistance from either provincial target recommendations or economic optimum analysis in determining their efficient N rates. Some of these type of results may also be encountered by maximum economic yield clubs in the province.

Conclusion

The discussion above has suggested that the characteristics of yield variability about the expected outcome at different rates of N are as important in making fertilizer decisions as the actual yield targets themselves. The objective is to maximize profit potential subject to acceptable levels of risk. It is seen that "moisture-modified" yield calibrations raise interesting questions about the variability characteristics of yield-N relationships of cereal crops.

Clearly, one challenge for yield calibration research is to keep this variability in mind when making fertilizer recommendations with the existing information base. A more significant second issue is to develop a data base which permits better prediction of the likelihood of conditions which are highly correlated with yield response. Moisture prediction information has been a focus of this paper but other areas deserving treatment are soil physical factors, effects of management practices, timing of operations, seeding date, etc. The need is even more urgent for field crops other than wheat, oats and barley.

Third, an underemphasized facet of the fertilizer input decision made by the farmer is the need to manage the risk associated with crop production. Focus on the probabilities and impacts of those factors which are correlated with yield response should permit farmers to narrow the range of their yield expectations for their field conditions. Higher N use may not be risk increasing, when combined with good probability information.

Finally, there is quite a need for investigating the statistical characteristics of what's been broadly called N recovery efficiency. It has components, variability characteristics and frequency distributions which probably vary by soil type, management and a host of other factors. But until the distributional characteristics are quantified and made available for farm level decision analysis, individual farmers may not be able to systematically apply economic techniques which identify best fertilization strategies.

REFERENCES

1. Alberta Department of Agriculture. Fertilizer Economics. Farm Planning Section, Farm Business Management Branch, Agdex 822-11, (July, 1985).

2. Bock, J.R. "Efficient Use of Nitrogen in Cropping Systems." In Nitrogen in Crop Production, Hauck, R.D. (Editor) . American Society of Agronomists, Madison, Wisconsin (1984):171-182.

3. de Jong, E. and D.A. Rennie. "Physical Soil Factors Influencing the Growth of Wheat." In Proceedings of Canadian Centennial Wheat Symposium, Nielsen, K.E. (Editor). Saskatoon: Modern Press, (1967):69-132.

4. Fehr, P. "Interpretation of Target Yield Fertilizer Recommendations." In Proceedings of the 14th Annual Manitoba Soil Science Meeting, Winnipeg (1970):79-90.

5. Just, R.E. and R.D. Pope. "Production Function Estimation and Related Risk Considerations." American Journal of Agricultural Economics 61(1979):276-84.

6. Manitoba Department of Agriculture. Crop Planning Guide, 1987.

7. Manitoba Provincial Soil Testing Laboratory. Target Yield Tables. Department of Soil Science, University of Manitoba, Winnipeg, (September, 1982).

8. McGill, K.S. "Nutrient Trends in Manitoba Soils: A Summary of Results from the Provincial Soil Testing Laboratory." In Proceedings 30th Annual Manitoba Soil Science Meeting, Winnipeg, Manitoba, (January, 1987):172-85.

9. Saskatchewan Department of Agriculture. Fertilizer Economics. Economics Branch, Farm Management Section, (March, 1986).

10. Sriramaratnam, S., D.A. Bessler, M.E. Rister, J.E. Matocha and J. Novak. "Fertilization Under Uncertainty: An Analysis Based on Producer Yield Expectations." American Journal of Agricultural Economics 69(1987):349-57.

11. Watt, J. and L. Arthur. "Opportunities and Prospects for Reduced Input Agricultural Systems: Wheat and Canola in the Prairie Provinces." Report to Agriculture Canada. Department of Agricultural Economics and Farm Management. University of Manitoba, Winnipeg, March, (1987).

Effect of Annual Legumes on the Nitrogen Status of Soils

M.R. Grenier and R.J. Soper

INTRODUCTION

Annual legumes are grown in Manitoba for seed and occasionally as green manure crops. Minimal data exists concerning the fate of legume derived N and fertilizer N within a soil-plant system when both sources of N are present together.

Crop residues or freshly added plant material will either, contribute or immobilize soil available N. Mineralization-Immobilization of soil N by the added plant residue will be dependent upon the nitrogen content of this added material. There exists a critical N content value, above which net mineralization of residue N will occur during decomposition, and below which net immobilization of soil N will occur.

The objectives of this study were to determine what this critical value might be for a Manitoba soil, and to determine the influence of the nitrogen content of plant residues at time of incorporation, on the contribution of nitrogen to a succeeding wheat crop.

MATERIALS AND METHODS

A randomized complete block experiment consisting of twelve treatments and three blocks was conducted in a growth chamber.

The soil used was obtained from the surface 15 cm of a Willowcrest series loamy fine sand. It contained 0.205 percent total nitrogen and 4.23 percent organic matter. The soil was air dried and passed through a 2 mm sieve.

Four lentil residues at various stages of growth and wheat straw were finely ground in a Willey mill prior to use. Fifty gram portions of each were thoroughly mixed with 5 Kg of soil. The total N content of the plant residues are given in Table 1. A control treatment of soil only was also included. Two levels of N: 0 and 100 mg/Kg were applied to above treatments. ^{15}N labelled ammonium sulphate containing 85 atom percent ^{15}N was used as the N source. The ammonium sulphate was applied by spraying and mixing 300 mls of solution onto the soil. Phosphorous as H_3PO_4 was applied at a rate of 50 mg/Kg to all treatments and where no nitrogen was applied S as H_2SO_4 was applied at a rate of 110 mg/Kg.

The 5 Kg lots of amended soil were placed in plastic pots, brought to field capacity and kept in a growth chamber at 24 degrees celsius. Pots were watered daily with distilled water to field capacity. After 30 days 8 wheat seeds (var. Columbus) were planted per pot and thinned to 4 after emergence. Plants were grown under a 16 hour photoperiod and day/night temperature was maintained at 22/18 degrees celsius. The plants were harvested 60 days after seeding. The roots were also collected by sieving while the soil was still moist.

The roots, above ground plant material and 100g sample of soil were dried, finely ground and analyzed for total nitrogen and ^{15}N content.

RESULTS AND DISCUSSION

Yield of wheat and total N content are shown in Table 2. Dry matter yield and total N content of wheat under both levels of added N were found to be related to the N content of the added residue Total N content was increased by amending the soil with high N content residues. This increase is thought to be the result of net mineralization of N from these high N rich residues. Figure 1 represents the change in quantity of N available to wheat due to additions of plant residues containing various amounts of N. The results demonstrate that if the nitrogen content of the added residue is greater than 1.5 percent nitrogen there will be a net mineralization of nitrogen upon decomposition; and conversely if the nitrogen content of the added residue is less than 1.5 percent nitrogen there will be a net immobilization of available nitrogen. From these data, the following equation is proposed:

$$\text{Kg of N released or immobilized from 1 Mg of residue in one year} = \text{mass of residue in Mg} \times (\text{N contained in 1 Mg (residue)} - 15)$$

Figure 2 illustrates what might happen with time. Wheat straw can vary in N content from 0.25 percent to 0.80 percent and will usually immobilize available N upon decomposition. Annual legume straws vary greatly in N content and either release small amounts of N or immobilize N. Annual legumes which are harvested before maturity will usually release N as they decompose. After approximately one year, it is assumed that all residues will contain the same amount of N (15 Kg) per Mg of original residue and have a half-life of 4 years.

Table 3 gives the results of field studies using open ended lysimeters to investigate dinitrogen fixation by annual legumes. Four crops were compared as to yield (above-ground dry matter and roots), N uptake of growth, viz. mid-pod for the annual legumes, milk stage for wheat and at maturity. From these data it is possible to calculate what effect each crop might have on the nitrogen status of soils. Except for lentils, the yields were rather good due to favorable growing conditions. Dinitogen fixation was highest for fababeans and lowest for lentils. The percent nitrogen in the crop derived from dinitrogen fixation had the same trend. Both sets of values are somewhat low considering the crop yields. This may have been due, in part or wholly, to an abundant supply of available soil nitrogen. The nitrogen removed as seed was in all cases greater than the dinitrogen fixed which means that the soil had a net loss in total nitrogen. We have found that generally the N removed as seed from annual legumes is equal to that fixed.

From these data and the proposed equation, an attempt was made to predict the amount of N which would be released or immobilized in the next year from each crop. At the early harvest, all legumes would release considerable quantities of N with fababeans being the best. If wheat were to be incorporated at this stage of growth, it would immobilize some available soil N. The results would be considerably

different if the crops were harvested at maturity and the seed removed. The annual legumes would either release or tie up small but significant amounts of available N while wheat would tie up considerable N. On average, the calculated difference between the annual legumes and the wheat crop is 59 Kg N/ha. From our data this would imply that non-legumes would require 59 Kg/ha less fertilizer N following an annual legume than following wheat.

The above-mentioned calculations are consistent with data obtained from three field experiments (Table 4). Yields of wheat following annual legumes were higher than those following wheat even when the wheat had been previously fertilized with adequate N. Nitrogen at 75 Kg/ha was enough to overcome N deficiencies for all sequences. Nitrogen applied at 25 Kg/ha to wheat following legumes gave a yield comparable to 75 Kg/ha applied to wheat following wheat. This seems to confirm that there is an approximately 50 Kg saving of N fertilizer if a farmer has an annual legume in the rotation. It should be noted that the annual legumes had a beneficial effect on the subsequent wheat crop which was not overcome by N additions. No doubt, there are many reasons for this finding, none of which were assessed.

SUMMARY

Mineralization-Immobilization of soil available N by added plant residues will be dependent upon a critical N content of the residue. From our studies this value was found to be 1.5 percent nitrogen.

The increase in available N following annual legumes appears to be mainly due to less immobilization of nitrogen upon decomposition of legume residue versus wheat residue.

We further conclude that a non-legume crop would require approximately 50 Kg/ha less fertilizer N following an annual legume than following wheat.

ACKNOWLEDGEMENTS

This work was supported by the Western Grains Research Foundation and the Economic and Regional Development Agreement.

Table 1. Total N content of added residues.

Plant type	Growth stage	% Total N content
Lentil	bud	3.1
Lentil	bloom	2.5
Lentil	mid-pod	2.1
Lentil	mature	0.9
Wheat	mature	0.5

Table 2. Dry matter yield and total nitrogen content of wheat at 60 days.

% N of added residue	Dry matter yield of wheat g/pot		Total N yield of wheat mg/pot	
	N added (mg/Kg)		N added (mg/Kg)	
	0	100	0	100
0.0	14.2	44.9	130.8	462.5
3.1	74.7	73.4	780.1	994.8
2.5	51.0	62.4	478.3	715.1
2.1	40.5	60.0	363.7	603.0
0.9	6.4	24.9	59.7	218.4
0.5	2.5	16.1	17.5	150.5

Table 3. Effects of crops on the nitrogen status of soils.

Crop	Grain yield kg/ha	N_2 fixed kg/ha	N in grain kg/ha	N in crop from N_2 fixation %	Predicted N release in one year	
					Mid-pod or milk	Maturity
					kg/ha	
Wheat	3653	0	96	0	-16	-57
Fababeans	3102	123	167	46	113	-19
Lentils	1353	31	60	20	57	26
Peas	2528	61	119	31	84	0

Table 4. Grain yield as affected by the addition of nitrogen and the previous crop (an average of three sites).

Previous crop	Nitrogen added (kg/ha)				
	0	25	50	75	100
Wheat with no N added	1824	2231	2769	2944	2900
Wheat with 100 kg . N/ha added	1863	2618	2738	2910	2826
Fababeans	2293	3000	3140	3203	3025
Lentils	2353	2816	3143	3254	3047
Peas	2490	2919	3023	3206	3111

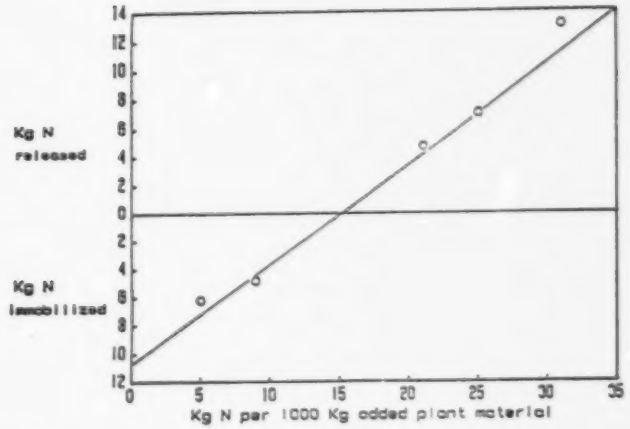


Figure 1. Change in quantity of N available to wheat due to additions of plant material containing various amounts of N.

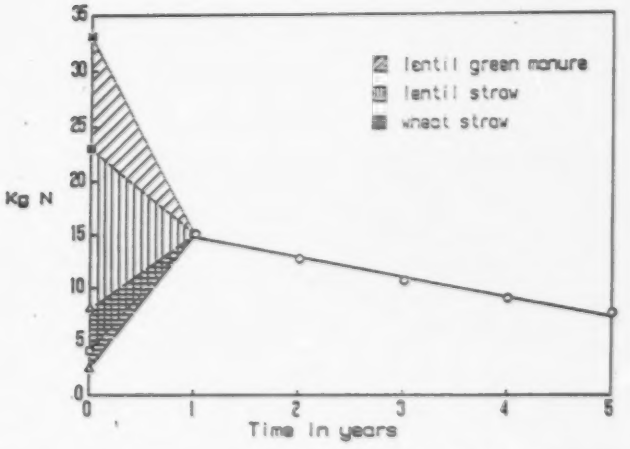


Figure 2. Nitrogen contained in soil from 1 Mg of added plant material with time.

The Response of Barley and Canola to Fertilizer Nitrogen on Organic Soils

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Introduction

Organic soils used for agriculture in Manitoba may contain from 1000 kg/ha to 4000 kg/ha of nitrogen in the 15 cm depth of soil tested. This nitrogen is mineralized by microbial action during the growing season at a rate depending on the soil temperature, moisture and specific composition of the organic material. Whereas it had been generally held that organic soils mineralized sufficient amounts of nitrogen for optimum crop growth, evidence from farmers and trials carried out by the Manitoba Peatland Farming Assn. indicated this was not always the case.

Unfortunately, the provincial soil testing lab had very little data on which to base fertilizer recommendations in the past and consequently this service was considered to be less than adequate for farmers on organic soils. For this reason, an Agri-Food project was conducted, beginning in October, 1985, to study various aspects of nitrogen availability and the nitrogen requirements of crops grown on organic soils. The specific objectives of the project were to gather enough field data to determine whether the NO3-N test used for mineral soils was reliable for organic soils and if so, to develop nitrogen fertilizer recommendations specifically for these soils. The project was carried out by the University of Manitoba Soil Science Dept. with assistance from the Manitoba Peatland Farming Association.

In order to provide nitrogen fertilizer recommendations based on fall or spring sampling of soils for NO3-N content, a number of factors needed to be understood:

1) The relationship between soil NO3-N levels and crop response to fertilizer N added.
2) The amount of organic N that is mineralized during the growing season.
3) The % efficiency of added fertilizer N.
4) The stability of NO3-N in the soil from fall to spring.

Methods and Materials

Twenty field experiments (12 with Argyle barley and 8 with Tobin canola) were carried out in the Eastern and Interlake areas of the province between October '85 and September '87 to obtain information on factors listed above. The crops were grown on a variety of organic soils which varied with respect to initial levels of soil NO3-N. The soils also differed in their depth of organic material, type of subsoil material, drainage, C:N ratios and their degree of decomposition.

The central experiments consisted of measuring crop response to added fertilizer nitrogen in a randomized complete block design with eight treatments and five replicates. Both barley and canola were seeded using a press drill into soils which were prepacked with a heavy drum roller. Basal fertilizer consisted of 50 kg/ha of P_2O_5 (11-55-0), 80 kg/ha K_2O (0 0 60), 44 kg/ha copper sulphate $5H_2O$ and 22 kg/ha $MnSO_4$ (barley only). The manganese and 20 kg/ha P_2O_5 were applied with the seed. The remainder of the P and all the K were banded into the soil preplant with a pressdrill. The copper sulphate was applied prior to tillage in a fine granular form with a Valmar pneumatic applicator and incorporated with a rototiller. Ammonium nitrate (34-0-0) treatments were surface broadcast postseeding at rates of 20, 40, 60, 90, 120, 180, and 240 kg/ha N. Soil NO3-N levels were measured in fall and again in spring to a depth of 120 cm to observe changes which occurred over winter. Soil NO3-N was also measured at harvest in plots which received no nitrogen fertilizer. Tissue samples were collected at random at heading stage and analyzed for possible nutrient deficiencies at each site. Grain yields and total dry matter were measured at harvest based on square meter samples. A composite sample of grain and straw from all five replicates for each treatment were analyzed for total N using a micro-kjehldahl analyzer.

Results and Discussion

(A) Relationship between soil NO3-N levels and crop response to fertilizer N.

Response to nitrogen fertilizer decreased with increasing initial soil NO3-N levels. Figure 1 shows %yield of barley vs. amount of soil NO3-N to a depth of 60cm. A quadratic regression line was used to test the relationship between %yield and NO3-N to various soil depths (table 1). The best relationship between %yield and soil NO3-N was obtained when NO3-N was measured to the 30 cm depth for barley and to the 60cm depth for canola. Percent yield was obtained using the formula:

$$P.Y. = \frac{\text{grain yield without N fertilizer}}{\text{maximum grain yield obtained with N fertilizer}}$$

Table 1. Relationship between percent yield and spring soil NO3-N levels measured to various soil depths

Depth of Soil Sampling	r^2 Value of Quadratic Regression Line	
	Barley	Canola
0-15 cm	.86	.81
0-30 cm	.86	.73
0-60 cm	.78	.86
0-90 cm	.71	.75

Total amount of N taken up by the crop at all sites on plots without N fertilizer was also plotted versus spring soil NO3-N levels measured to a depth of 60 cm (Fig. 2). There was a very high degree of fit for a quadratic regression equation at all depths for the barley and at 30, 60, and 90 cm depths for the canola (Table 2).

Table 2. Relationship between total N uptake and spring soil NO3-N levels measured to various depths.

Depth of Soil Sampling	r^2 Value of quadratic regression line	
	Barley	Canola
0-15 cm	.89	.72
0-30 cm	.91	.88
0-60 cm	.86	.80
0-90 cm	.86	.81

(B)Mineralization of Soil Nitrogen during the Growing Season

The apparent amount of N mineralized during the growing season under each crop at each site was calculated using the following expression:

Amount of N mineralized=
[NO3-N to 120 cm depth in check plot at harvest + total N taken up by the crop in check plot - spring soil NO3-N to 120 cm].

Apparent amounts of N mineralized varied considerably between sites especially among sites which contained very high levels of spring NO3-N. Part of the variability at the sites with high NO3-N levels was probably due to spatial variation of NO3-N and error of sampling. Variability in amount of N mineralized could also be a result of denitrification and leaching losses in plots with very high concentrations of NO3-N. Amounts of N mineralized for sites which contained low levels of NO3-N showed much less variability. Mineralization rates at these sites averaged 33 kg/ha and ranged from 7 to 73 kg N/ha. These measurements indicate that perhaps amounts of N mineralized in an organic soil may be similar or slightly higher than a typical mineral soil. Amounts of N mineralized in typical Manitoba mineral soils during the growing season have averaged about 25 kg N/ha under crop (personal correspondence with R.J. Soper). There was no apparent relationship between observed N mineralization and C:N ratio of the soil material.

Table 3. Amounts of N mineralized during the growing season at five sites low in NO3-N.

Site	Spring NO3-N to 120 cm	N mineralized over growing season kg/ha Barley	Canola	Soil C:N Ratio
Sundown	21	23	22	15.4
S. Sisters	25	25	59	23.1
LaBroquerie	16	73	56	12.6
Medika	66	11	7	16.5
Washow Bay	48	23		15.4

Average of all measurements: 33.2 kg/ha

(C) Fertilizer N Required to achieve Maximum Grain Yields.

Maximum grain yield at all sites averaged 2811 kg/ha for barley and 1122 kg/ha for canola. These yields represent about 94% and 85%, respectively, of average farm yields in Manitoba in 1986. The rate of N fertilizer required to achieve 90% of maximum yield usually varied inversely with spring soil NO3-N levels (Table 4). Two exceptions were the sites at Teulon(1) and Marchand where crops responded slightly to high rates of N fertilizer despite high soil NO3-N levels in spring. The amount of N fertilizer required to achieve maximum economic yield varied inversely with spring soil NO3-N more consistently than 90% maximum yield, with the exception of the site at Marchand.

Table 4. Rates of N fertilizer required to achieve 90% of maximum grain yield (MGY) and maximum economic yield (MEY) at twelve organic soil sites.

Site	Soil NO3-N to 60 cm depth kg/h	Rate of Fertilizer N (kg/h) for MGY and MEY Barley MGY	Barley MEY	Canola MGY	Canola MEY
S. Sisters	4	90	90	60	60
Sundown	12	120	120	60	120
LaBroquerie	13	240	90	40	60
Washow Bay	36	20	40		
Medika	38	40	90	0	40
Whitemouth	77	0	0		
Piney	130	0	0	0	0
Riverton	130	20	20		
Teulon(2)	151	20	20		
Elma	193	40	20	0	0
Marchand	260	90	90	240	240
Teulon(1)	280	20	20	240	40

Price assumptions above: N fertilizer $22/tonne
Canola $250/tonne
Barley $50/tonne

(D)Utilization of Fertilizer Nitrogen

Percent utilization of fertilizer nitrogen was calculated as follows:

$$\% \text{ Utilization} = \frac{[\text{ total N uptake in fertilized treatment - N uptake in non-fertilized treatment }]}{\text{N fertilizer added}}$$

Percent utilization of fertilizer nitrogen averaged 45% for barley(Table 5) and 28% for canola(Table 5b). The % utilization of fertilizer N was calculated only for sites which contained relatively low soil NO3-N levels.

Table 5a. Percent Utilization of fertilizer N in soils with low spring NO3-N levels.

BARLEY	% utilization of fertilizer N at various application rates(kg/h)				
Site	20	40	60	90	Average
LaBroquerie	40	24	28	23	29
Medika	37	59	41	44	34
Washow Bay	90	48	34	31	51
Sundown	84	61	63	52	65
S.Sisters	27	54	.51	63	49
	5 Site average:		45.5%		

Table 5b. % utilization of fertilizer N
(CANOLA) at various application rates(kg/h)

Site	20	40	60	90	Average
LaBroquerie	17	24	26	18	21
Medika	0	29	26	8	16
Sundown	44	36	24	22	32
S.Sisters	56	43	46	28	43
	4 Site average:				28%

(E)Stability of SOIL NO3-N from Fall to Spring

Nitrate nitrogen levels remained constant or increased slightly from fall to spring for sites with low nitrate levels. The exceptions were LaBroquerie and Sundown where rising spring water tables were likely the cause of some overwinter losses of soil nitrate. Sites with high levels of soil NO3-N showed very large spatial variation in NO3-N. Thus,it is difficult to assess the degree of NO3-N stability in the soils. Despite the large spatial variation however,it appears that no large losses of NO3-N occurred (Table 6).

Table 6. Changes in NO3-N levels from fall to spring at twelve organic sites.

Site	NO3-N (kg/ha) to 60 cm depth FALL	SPRING	DIFFERENCE
S. Sisters	5	5	0
Medika	18	38	+20
Washow Bay	23	36	+13
Sundown *	23	12	-11
LaBroquerie *	27	12	-15
Whitemouth	83	77	-6
Teulon2	99	151	+52
Riverton	105	130	+25
Piney	130	130	0
Elma	137	193	+56
Teulon1	152	280	+128
Marchand	263	259	-4

* these sites were inundated with water in spring

Summary and Conclusions

Although these experiments were conducted only on twelve sites over a period of two years,sufficient information was obtained to improve N recommendations for organic soils. The data indicates that:

1)Soil test fertilizer recommendations can be based on soil NO3-N levels measured to a depth of 30 or 60 centimeters. Although good relationships were obtained between response to fertilizer and NO3-N measured to a 15

cm depth, it would be prudent to continue basing fertilizer recommendations on samples taken to 60 centimeters until additional research supports the shallower sampling depths.

2)Amounts of N mineralized during the growing season averaged 33 kg/ha for sites initially low in NO3-N. Such an amount is not sufficient to provide adequate nitrogen for good crops of barley and canola on soils low in NO3-N at time of seeding. Also, the amounts of N mineralized were similar to that obtained from studies on mineral soils.

3)Nitrogen recommendations for barley and canola crops to be grown on soils testing low in NO3-N should range between 40 to 90 kg/h.

4)N fertilizer efficiency averaged 45% for barley crops and 28% for canola. There is too little data here to suggest that the 50% efficiency factor presently assumed for nitrogen fertilizer should be altered for organic soils.

5)Soil NO3-N is fairly stable overwinter in soils with good drainage. The data indicates that an increase of 0 to 20 kg/ha nitrate-N may be expected in soils with good drainage and low initial nitrate levels between fall and spring.

Figure 1.

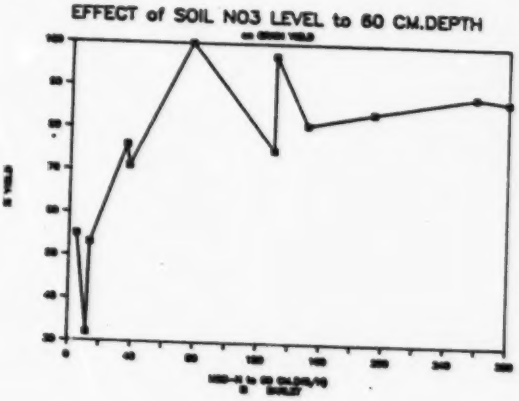
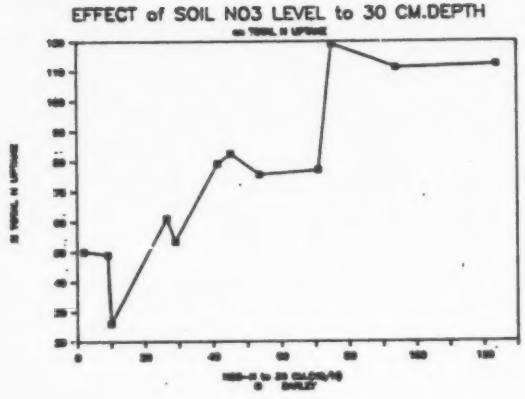
Figure 2.